COGNITIVE, AFFECTIVE, BEHAVIORAL AND MULTIDIMENSIONAL DOMAIN RESEARCH IN STEM EDUCATION: ACTIVE APPROACHES AND METHODS TOWARDS SUSTAINABLE DEVELOPMENT GOALS (SDGS)

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PUBLISHED IN: Frontiers in Psychology and Frontiers in Education

frontiers Research Topics

frontiers

ISSN 1664-8714
ISBN 978-2-88974-981-2
DOI 10.3389/978-2-88974-981-2

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COGNITIVE, AFFECTIVE, BEHAVIORAL AND MULTIDIMENSIONAL DOMAIN RESEARCH IN STEM EDUCATION: ACTIVE APPROACHES AND METHODS TOWARDS SUSTAINABLE DEVELOPMENT GOALS (SDGS)

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Citation: Jeong, J. S., Gonzalez-Gomez, D., Guo, J., Kraly, J. R., eds. (2022). Cognitive, Affective, Behavioral and Multidimensional Domain Research in STEM Education: Active Approaches and Methods towards Sustainable Development Goals (SDGs). Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88974-981-2

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frontiers in Psychology

EDITORIAL
published: 31 March 2022
doi: 10.3389/fpsyg.2022.881153

Editorial: Cognitive, Affective, Behavioral, and Multidimensional Domain Research in STEM Education: Active Approaches and Methods Towards Sustainable Development Goals (SDGs)

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Keywords: STEM education, active methodologies, sustainability, climate change, innovative, sustainable education, educational psychology, Sustainable Development Goals (SDGs)

Editorial on the Research Topic

Cognitive, Affective, Behavioral, and Multidimensional Domain Research in STEM Education: Active Approaches and Methods Towards Sustainable Development Goals (SDGs)

OPEN ACCESS

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *22 February 2022*
Accepted: *04 March 2022*
Published: *31 March 2022*

Citation:
Jeong JS and González-Gómez D (2022) Editorial: Cognitive, Affective, Behavioral, and Multidimensional Domain Research in STEM Education: Active Approaches and Methods Towards Sustainable Development Goals (SDGs). Front. Psychol. 13:881153. doi: 10.3389/fpsyg.2022.881153

This Research Topic consists of 15 articles on various aspects and methodologies of active and sustainable Science, Technology, Engineering, and Mathematics (STEM) education toward educational psychology domain research contributed to by 49 authors. At the time of writing the Research Topic, the articles published have been checked online more than 24,000 times and received abundant citations in the scientific literature.

The topic theme, "STEM education," is an umbrella term for the approaches and methods from different research disciplines and areas, targeted at the improvement of Sustainable Development Goals (SDGs) and the cognitive, affective, behavioral, and multidimensional domain in both academic, professional, and industrial personnel who are involved in this field with their everyday work. Here, the various educational psychology domains are getting increased attention in relation to STEM and SDGs. In the same context, it is still challenging and inspiring because this educational psychology domain needs to reflect the current renewable and sustainable situations that are required to follow and achieve the SDGs in STEM education. With various active approaches and methods becoming available, all these ideas and thoughts in the educational psychology domain could be integrated into the area of STEM toward the SDGs that can diagnose and analyze various peoples' cognitive, affective, behavioral, and multidimensional patterns as well as their peculiarities.

Therefore, this Research Topic aims to offer and contribute to a corpus of solid research for concentrating and addressing the challenges required to stipulate an adequate STEM and Sustainable Development Education (SDE) toward SDGs to scholars and professionals of different educational degrees and backgrounds in the cognitive, affective, behavioral, and multidimensional research domain. Although the SDGs are progressively establishing a part of the curricula of numerous educational institutions, efforts must be made to ensure proper implementation and development of SDE, and interdisciplinary study of sustainability-oriented topics looking for the SDGs in higher education, as well as fresh viewpoints on current and existing challenges.

The 15 articles discuss the major trends in active and sustainable STEM education toward educational psychology domain research. The articles are now summarized in the order of articles most viewed in the topic proposed (the highest rank is "1"):

1. *A STEM Course Analysis During COVID-19: A Comparison Study in Performance and Affective Domain of PSTs Between F2F and F2S Flipped Classroom* (Jeong and González-Gómez). This is an original research article to compare and examine two different instruction situations with an identical teaching methodology, Face-To-Face (F2F) and Face-To-Screen (F2S) flipped methodology, on the performance and affective domain of Pre-Service Teachers (PSTs) in a STEM course. Here, the results indicated F2F was preferred over F2S although F2F-F2S transition was an effective procedure. Thus, it will allow PSTs to be more interactive in an online setting for their future application iof STEM courses (5267 total views).
2. *Student Engagement in Mathematics Flipped Classrooms: Implications of Journal Publications From 2011 to 2020* (Lo and Hew). This is a systematic review to examine the comparative studies' results, which were published between 2011 and 2020. It summarized this instructional approach effects along with traditional lecturing on the behavioral, emotional, and cognitive engagement of students within mathematics courses. Here, the results had significant implications for future flipped-classroom practice such as students solving real-life problems, and for research on student engagement in mathematics education (2,751 total views).
3. *An Exploratory Study Interrelating Emotion, Self-Efficacy, and Multiple Intelligence of Prospective Science Teachers* (Hernández-Barco et al.). This is an original research article to identify the learning styles of science teachers along with the theory of multiple intelligences. It studies their self-efficacy perception concerning the different scientific contents they would be required to instruct in and ascertaining correlations between these variables. Here, the results showed that these future teachers received greater refusal toward Physics and Chemistry than toward Biology and Geology. Thus, it is conceivable to establish emotional differences that the future teachers felt toward science according to which track they took in their pre-university backgrounds (2,102 total views).
4. *Promoting Middle School Students' Science Text Comprehension via Two Self-Generated "Linking" Questioning Methods* (Sason et al.). This is an original research article to measure two forms of reading approaches as a quasi-experimental study: Self-generated questions either connecting to prior knowledge (Extra-Text) or connecting between the text's parts (Within-Text). Here, the results from both short- and long-term evaluations indicated that those learners trained to generate questions about within-text connections reached significantly higher science text comprehension achievements than the other groups. Also, the findings may contribute to the support methods' design and teaching approaches for supporting general literacy and, in particular, scientific literacy (2,014 total views).
5. *When to Scaffold Motivational Self-Regulation Strategies for High School Students' Science Text Comprehension* (Michalsky). This is an original research article to examine the important role motivation plays in reading comprehension for science students in a 14-week quasi-experimental study. Here, outcomes suggested meta-motivational scaffolding delivery as a possibly important means for reassuring the scientific literacy of students and effortful determination with challenging science assignments. Especially, it was at the reflection-before-action phase for looking ahead and at the reflection-on-action stage for looking back. However, for this preliminary study, more theoretical and practical implications were deliberated to address the increasing challenges in science schoolwork (1774 total views).
6. *A Study of Disposition, Engagement, Efficacy, and Vitality of Teachers in Designing Science, Technology, Engineering, and Mathematics Education* (Lin et al.). This is an original research article to propose and test a theoretical model of how STEM e-learning affects teachers' perceptions of engagement, disposition, and efficacy, which can affect their vitality when they design STEM education. Here, the teachers' disposition could predict lesson design engagement. For both factors, they predicted effectiveness for designing STEM e-learning in turn, showing that well suited STEM instructors must not only be able to plan a STEM curriculum but also have a positive STEM education perception (1,218 total views).
7. *Emotional and Cognitive Preservice Science Teachers' Engagement While Living a Model-Based Inquiry Science Technology Engineering Mathematics Sequence About Acid-Base* (López-Banet et al.). This is a brief research report article focusing on the requirements of science teachers to carefully check the classroom teaching methodologies, to confirm that students are given chances to improve proper comprehension of acid/base models and concepts. The results indicate that there are noteworthy relationships between emotions and knowledge, which are different according to the skill concerned. Also, substantial correlations between emotions have been discovered (1,053 total views).
8. *Evolution of Prospective Secondary Education Economics Teachers' Personal and Emotional Metaphors* (Mellado et al.). This is an original research article to examine prospective economics teachers' personal and emotional metaphors about the roles as teachers. Then, their students examined their drawings and answers to open questions. The results showed that in the role of teachers, the most common metaphors used in both questionnaires were cognitivist and constructivist. Also, the findings' comparison before and after the teaching practicum exposed that there were no changes in most of the participants' metaphors and linked models (1,023 total views).
9. *Comparison Between Performance Levels for Mathematical Competence: Results for the Sex Variable* (García Perales and Palomares Ruiz). This is an original research article to utilize an ex post facto. It is a descriptive and quantitative methodology to assess the 3,795 5th-year elementary school students' results, using the online version of the Evaluation Battery for Mathematical Ability (BECOMA On). Here, the results were also examined based on sex that showed statistically significant differences in the highest performance level. Thus, this research emphasized a diagnostic breach in

the higher capacity students' identification, showing education systems' pending challenge for the educational inclusion of all students (878 total views).

10. *Detailed Emotional Profile of Secondary Education Students Toward Learning Physics and Chemistry* (Dávila-Acedo et al.). This is an original research article to present research needs to classify the K-7 to K-10 students' emotions toward Physics and Chemistry learning. Currently, there is a decreasing number of students who select programs associated with science. The results indicated that a decrease was noticed in the positive emotions' mean rate, which are joy, fun, and tranquility from K-8 to K-10. An increase in negative emotions, such as boredom, anxiety, disgust, fear, nervousness, worry, and sadness, was also detected (790 total views).
11. *Endorsing Sustainable Enterprises Among Promising Entrepreneurs: A Comparative Study of Factor-Driven Economy and Efficiency-Driven Economy* (Raza Sargani et al.). This is an original research article on the Theory of Planned Behavior (TPB), which aimed to scrutinize the relationship between predecessors on sustainable enterprise purpose and sustainable value formation. The research features the work values' importance in choosing programs for sustainability-oriented entrepreneurship. It can help candidates to advance their entrepreneurial capabilities and knowledge platform, which will inspire them to become sustainable upcoming entrepreneurs (753 total views).
12. *Prompting Socially Shared Regulation of Learning and Creativity in Solving STEM Problems* (Michalsky and Cohen). This is an original research article to check the influence of three support types (question prompts intended to support Socially Shared Regulation of Learning (SSRL), creative thinking, or a combination of both) on the individual participations in SSRL procedures and on their knowledge attainment. It used a sample of 104 seventh graders in accelerated science classes. Here, the findings fortify the SSRL-directed question prompts' case as a means to improve students' engagement in problem-solving jobs (661 total views).
13. *Effectiveness of Metacognitive Regulation Intervention on Attention-Deficit–Hyperactivity Disorder Students' Scientific Ability and Motivation* (Zheng et al.). This is an original research article to investigate the Metacognitive Regulation (McR) intervention effect on Attention-Deficit–Hyperactivity Disorder (ADHD) students' astronomy knowledge attainment and learning motivation. After a 15 week intervention, the results displayed that the experimental group of students achieved significantly better than the control group ones in learning motivation, scientific abilities, and metacognition. Also, the findings recommended that the McR intervention is an effective method for enlightening the ADHD students' learning abilities for science knowledge (532 total views).
14. *A Preliminary Study Comparing Pre-Service and In-Service School Principals' Self-Perception of Distributed Leadership Competencies in relation to Teaching and Managerial Experience* (Cebrián et al.). This is an original research article to validate the works that have concentrated on studying the self-conception of school principals. It showed their dispersed leadership competencies regarding their teaching and managerial experience. This preliminary work offers visions into the relevance of pre-service or in-service school principals with training and professional development programs on sustainability. It disseminated leadership that allows them to authentically retain the school community, advance innovative instructions, and lead change toward more sustainable schools (26 total views).
15. *The Mediating Role of Critical Thinking in the Relationship between EFL Learners' Writing Performance and their Language Learning Strategies* (Esmaeil Nejad et al.). This is an original research article to investigate the intervention ability of Critical Thinking (CT) between the important means of language learning and English as a Foreign Language (EFL) learners' writing approaches. Here, the results presented that there was a substantial relationship among (a) learning strategies and learners' writing performances, (b) the sub-sets of learning strategies and learners' writing performances, and (c) CT and learners' learning strategies. Thus, the findings may offer a view into facilitating EFL learners to contemplate and write more critically (15 total views).

STEM education can be contemplated as inter- and multi-disciplinary interactions for forming fundamental factors in teaching and learning (Jeong and González-Gómez; Lin et al.; Michalsky and Cohen). Here, for sustainable development and SDGs, STEM education can be associated with knowledge-acting values of sustainability education (Raza Sargani et al.; Cebrián et al.). Also, there is a robust connection to science and mathematics education in the same context of sustainable development and SDGs (Sason et al.; Lo and Hew; García Perales and Palomares Ruiz). However, it is still not associated with a distinct research area that could have its own values, approaches, dimensions, aptitudes, and scientific skills. Equally, in various educational levels, sustainability STEM was a starting step although they had implemented different transforming societies/cultures by hiring academics, leaders, and entrepreneurs as key personnel (Hernández-Barco et al.; Michalsky; Mellado et al.; Dávila-Acedo et al.; López et al.; Jeong and González-Gómez). Accordingly, it was crucial to reflect elementary-, mid-, high-schools' (García Perales and Palomares Ruiz; Michalsky and Cohen; Hernández-Barco et al.; Michalsky; Mellado et al.; Dávila-Acedo et al.), universities' (López et al.; Jeong and González-Gómez; Zheng et al.; Lo and Hew), and professionals' (Raza Sargani et al.; Esmaeil Nejad et al.) characteristics that were shifting moderately and slowly.

The decade of education for sustainability development (DESD) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in the UN and UNESCO 2015–2030 Agenda amalgamated the beliefs, philosophies, purposes, and movements of sustainable education and SDE (Jeong and González-Gómez). In the context of challenging circumstances mentioned earlier, a pedagogical possibility can link current educational structures' niche with long-term and lifelong sustainability STEM education (Raza Sargani et al.; Cebrián et al.; Jeong and González-Gómez). In the various educational domains, it should be a segment of a universal procedure offering sustainability STEM education (Lin et al.; Michalsky and Cohen). Also, it can outline its aims together with information and knowledge to individuals that will readdress the effects of their aspect (García Perales and Palomares Ruiz; Esmaeil Nejad et al.). Particularly, it was enhanced to offer better comprehension of notions regarding STEM sustainability, was designed for the realization of information, knowledge, abilities, and worth, and was reorientated to the curricula in sustainability STEM education (Jeong and González-Gómez; Lin et al.; Michalsky and Cohen). Here, sustainability education can be directed into transformative learning, which was a cultural modification in STEM education for possible awareness and social, economic, and environmental interdependence for individuals. Thus, in the same transformative learning environment, it highlighed the importance of instructors who could support students who should realize much more self-regulating and consistent objectives (Michalsky; Mellado et al.; Zheng et al.).

In the context of educational psychology, much of the research indicated a cognitive, affective, behavioral, and multidimensional domain in both academic and industrial people who are involved in this field in their daily work (Mellado et al.; Hernández-Barco et al.; Zheng et al.; Jeong and González-Gómez). Here, different types of positive emotions fostered and emphasized motivation, metaphor, interest, and competence. Students were experienced in the aspect of the proposed questions and its practicality and were encouraged by a collaborative and cooperative environment (Hernández-Barco et al.; Michalsky; Mellado et al.; López-Banet et al.; García Perales and Palomares Ruiz; Dávila-Acedo et al.). Active approaches and methods also had a positive contribution to the educational psychology domain, with students' achievement, motivation, metaphor, competence, and collaboration improving in their class (Jeong and González-Gómez; Lo and Hew; López-Banet et al.; Michalsky). Along with the context mentioned in various teaching and learning methods, emotions played a primary position because they were highly associated with the cognitive feature. Positive emotions' presence for students in a subject aided their learning whereas negative emotions' generation restricted it (Hernández-Barco et al.; Michalsky; Mellado et al.; López-Banet et al.; García Perales and Palomares Ruiz; Dávila-Acedo et al.). For various students and professionals at different levels, it indicated that considering the negative familiarities and problems with sustainability STEM education could allow educators to better comprehend their negative attitude and low self-efficacy toward sustainability STEM teaching. It extended to the interrelation between self-efficacy, beliefs, and attitudes toward sustainability STEM if changes could lead to their teaching practices' improvement (López-Banet et al.; Jeong and González-Gómez; Hernández-Barco et al.; Mellado et al.). Therefore, it is essential to address specific research on cognitive, affective, behavioral, and multidimensional domain research in STEM education along with active approaches and methods toward SDGs.

The Research Topic offered a substantial number of articles on STEM education issues related to sustainability and educational psychology (Jeong and González-Gómez; Lin et al.; Michalsky and Cohen), incorporating SDGs in various levels (Raza Sargani et al.; Cebrián et al.), active methods (like flipped classroom) to improve engagement in mathematics education (Lo and Hew), middle-school science literacy achievements as an educational psychology (Sason et al.), pre-service teachers' affective domain study toward science courses (Hernández-Barco et al.), high-school students' science motivation as an active scaffolding method (Michalsky), emotional metaphors for economic teachers in secondary education (Mellado et al.), emotional and cognitive aspect for pre-service science teacher (López-Banet et al.), mathematical competence and performance comparison (García Perales and Palomares Ruiz), secondary students' detailed emotional profiles toward physics and chemistry (Dávila-Acedo et al.), metacognitive regulation intervention for ADHD students' scientific ability and motivation (Zheng et al.), and the critical thinking mediating role for EFL learners' writing performance and strategies (Esmaeil Nejad et al.).

Therefore, this Research Topic demonstrated and reiterated the results of theoretical, methodological, and empirical research on teaching and learning, competencies and assessment, policy, program development and implementation, instructor preparation, community- and project-based learning, institutional collaborations and partnerships, and other relevant subjects. With 15 articles published, we can observe that special emphasis was placed upon innovative teaching approaches and methodologies. They have been proven to be relevant on STEM education, not only considering the cognitive domain of the learning process but also the affective, behavioral, and multidimensional domains that all improved and were targeted toward furthering the SDGs.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers in Psychology

ORIGINAL RESEARCH
published: 26 October 2020
doi: 10.3389/fpsyg.2020.595745

Promoting Middle School Students' Science Text Comprehension via Two Self-Generated "Linking" Questioning Methods

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This quasi-experimental study examined training in two types of reading strategies: self-generated questions either connecting to prior knowledge (Extra-Text) or connecting between the text's parts (Within-Text). Immediate and long-term effects were assessed on ninth graders' science text comprehension, versus an untrained control group. The three student groups (N = 193) received the same study unit of scientific texts and accompanying tasks, either with/without training in self-generated questioning. PISA-based science literacy assessments (phenomenon identification, scientific explanation, and evidence utilization) were collected at baseline, immediately after intervention, and at 4-month follow-up. Results from both short- and long-term assessments indicated that those learners trained to generate questions about within-text connections reached significantly higher science text comprehension achievements than the other two groups – students trained to generate questions connecting to their prior knowledge and control students who received no support for generating questions. Findings may contribute to the design of support methods and teaching strategies for promoting literacy in general and scientific literacy in particular.

Keywords: scientific literacy, reading strategies, reading comprehension, self-generated questioning, middle school, long-term maintenance, prior knowledge, within-text connections

OPEN ACCESS

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *17 August 2020*
Accepted: *22 September 2020*
Published: *26 October 2020*

Citation:
Sason H, Michalsky T and Mevarech Z (2020) Promoting Middle School Students' Science Text Comprehension via Two Self-Generated "Linking" Questioning Methods. Front. Psychol. 11:595745. doi: 10.3389/fpsyg.2020.595745

INTRODUCTION

The importance of enhancing science literacy among students of all ages has been emphasized by recent reforms in science education (National Research Council of National Academies, 2011; Organisation for Economic Co-operation and Development [OECD], 2014, 2016, 2017; National Academies of Sciences, Engineering and Medicine, 2016). The Program for International Student Assessment (PISA) defined science literacy as: "The capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (Organisation for Economic Co-operation and Development [OECD], 2003, p. 15). Specifically, these educational reforms encourage the reading of scientific texts, calling on students to "learn how to access scientific information from texts and evaluate and interpret the information they have acquired" (National Research Council of National Academies, 2003, p. 40).

Yet, research has indicated that, when reading scientific texts, students face significant challenges in three major skills for scientific literacy: phenomenon identification, scientific explanation, and evidence utilization (e.g., McNamara, 2017). Namely, many students show substantial difficulties when asked to *identify scientific phenomena* from such texts (Rop, 2003; Michalsky, 2013). Moreover, students often struggle when asked to *give scientific explanations* and to formulate hypotheses based on the texts (Cromley et al., 2010). Finally, when asked to *evaluate and interpret experimental evidence* described in texts, students tend to reject, misinterpret, or ignore data that do not match their existing naïve theories and misconceptions (McNamara, 2017). These three skills' centrality is also evident from their appearance in international PISA testing of scientific literacy in recent years (Organisation for Economic Co-operation and Development [OECD], 2016, 2017).

These and similar additional research findings on middle-school students (Chin and Osborne, 2010; Fang and Wei, 2010; Okkinga et al., 2018) call for the development of tools for fostering readers' scientific text comprehension. One highly effective method is for learners to generate self-questions before, during, and/or after reading a passage (e.g., "Do I understand the main idea in this paragraph?" or "What do I already know about this issue?"), aiming to help them monitor and manage their reading comprehension (Gunn, 2008; Kaberman and Dori, 2009; Joseph and Ross, 2018). The process of generating self-addressed questions assists readers in developing higher metacognitive self-regulation concerning the learning process (Moseley et al., 2016). This includes increased focus on critical information; better awareness about texts' meaning; and improved operations for monitoring understanding, correcting errors, and successfully completing accompanying assignments (Chin and Osborne, 2010; Crabtree et al., 2010; Herscovitz et al., 2012; Wood et al., 2015; Cameron et al., 2017).

Although researchers have begun to investigate students' self-questions during scientific text reading for their effects on science achievements and scientific literacy (Kaberman and Dori, 2009; Moseley et al., 2016), little empirical attention has been given to the relative effectiveness of different reading strategies underlying such student-generated self-addressed questions. The current study compared two types of self-generated questions that comprise "linking" reading strategies – either connecting to prior knowledge (Extra-Text) or connecting between the text's parts (Within-Text) – for their immediate and long-term effects on ninth graders' science text comprehension, versus an untrained control group.

Bridging (Within-Text) Versus Elaborating (Extra-Text) "Linking" Strategies

Research has demonstrated that successful comprehension of scientific texts relies on readers' ability to draw links and connections between various sources of information (McNamara, 2007; Kostons and Van Der Werf, 2015). McNamara (2004, 2009, 2017) investigated two essential "linking" strategies for scientific text reading comprehension: bridging inferences and elaboration.

Bridging Inferences: Within-Text Links

In the bridging-type strategic process, readers connect between pieces of information that they glean from different parts of the reading task in order to understand the relations between separate sentences, paragraphs, and accompanying visual-graphic representations (McNamara, 2017) like graphs, tables, or diagrams. Making meaning of what has been read derives from the ways in which the various parts and ideas of the science task connect (Kuo and Anderson, 2006). The following presents two examples for bridging activity accompanying a PISA-like text called "Light Cigarettes" for promoting scientific literacy (National Authority for Measurement and Evaluation in Education [RAMA], 2010):

- Bridging multiple parts of a graph: When asked if people who stopped smoking in their 1930s had a similar chance of developing lung cancer as people who never smoked, students need to find the links between different data appearing within a graph that presents information on smokers' and non-smokers' ages, quantity of cigarettes smoked, number of years they smoked and type of cigarettes.
- Bridging two parts of text: When asked why the government prohibited labeling such as "lite" for cigarettes in which the amount of tar is low, students need to connect the passage of text describing studies conducted on smokers of "lite" cigarettes and the passage of text describing those cigarettes' contents.

Often, science tasks do not explicitly pinpoint how the different bits of given written and visual information may complement or clarify one another; readers are expected to infer their causal, temporal, spatial, conceptual, hierarchical, and other interconnections (McNamara, 2007; Barzilai and Eilam, 2018; Jian, 2018). Researchers have asserted that readers' difficulty in coordinating and connecting (bridging) between different pieces of information that appear within the text often leads to inefficient and decentralized reading (Mason, 2004; Cromley et al., 2010; McNamara, 2017). Research has supported the importance of text-focused reading strategies, which stimulate learners to make connections within the text. Best et al. (2005) suggested that creating inferences between sentences and ideas in science texts can fill perceptual gaps between the learner's prior knowledge and the new knowledge and help students compete/deal with the level of difficulty of the texts in science books.

O'Reilly et al. (2002) and O'Reilly and McNamara (2007) added that skills for linking parts within a text can help learners to locate comprehension errors while reading the text and to correct them. This builds a system of judgment and control, which allows learners to assess the quality of their learning processes and outputs. Thus, within-text linkages help learners apply meta-comprehension skills that optimize accuracy and that help track progress toward learning goals. To be noted, the inferences made by students in O'Reilly and McNamara's (2007) studies resulted from instructions given by the teacher to perform such linking activities, and not via students' own self-questioning.

Elaboration: Extra-Text Linkages With Prior Knowledge

In the elaboration-type strategic process, readers link the current text to related knowledge that they already possess. For instance, readers of a text on heart disease need to connect "Coronary artery disease occurs when the arteries become narrowed and hardened" to their previous knowledge that the heart muscle receives blood from the arteries. In addition, readers can also logically apply prior general knowledge to deduce that narrowed arteries would decrease blood flow to the heart muscle, which would cause a lack of oxygen supply that could potentially result in a heart attack. Another example for elaboration activity accompanies a PISA-like text called "Marching and Drinking" for promoting scientific literacy (National Authority for Measurement and Evaluation in Education [RAMA], 2012). In this case, the text referred to the sensation of warmth in the body that occurs when drinking alcohol. To understand the biological processes, readers need to connect to prior knowledge that blood vessels dilate while drinking alcohol, resulting in blood flow at a lower pressure, which causes the body to lose heat and cool down (Organisation for Economic Co-operation and Development [OECD], 2009b).

Previous studies have found that when students connect their prior knowledge to science text reading, their reading comprehension achievements improve (Kendeou and Van Den Broek, 2007; Moos and Azevedo, 2008; Kaberman and Dori, 2009; Ozuru et al., 2009; Moseley et al., 2016; Joseph and Ross, 2018). Kendeou and Van Den Broek (2007) argued that readers cannot be expected to understand the text if they lack the ability to link the new information with their prior knowledge. According to Kendeou and Van den Broek (2007), the previous knowledge that readers bring with them to the text is a tool that allows them to understand the meaning of the words, sentences, and ideas found in the text. Cromley and Azevedo (2007) even explained that the process of searching for a text's meaning and understanding its main message is defined as a process of building logical connections and completing missing information that relies on the help of the reader's prior knowledge. Prompts to construct connections between previous and new knowledge were incorporated into Michalsky's (2013) IMPROVE self-regulation method, using externally generated (rather than self-generated) self-questions such as "What are the similarities/differences between the science text that I am currently reading and the texts that I have read in the past, and why?"

The Current Study

To examine the effectiveness of two different types of self-generated linking self-questions, as reading strategies for promoting middle-school science readers' scientific literacy, the present quasi-experiment aimed to compare reading comprehension growth among three groups of students receiving the same study unit of ninth-grade biology texts and tasks. While engaging in this study unit, the Bridging (Within-Text) group underwent training to create self-questions that link between different parts within each task (within the text and between the text and its accompanying visual-graphic representations), whereas the Elaboration (Extra-Text) group was trained to create self-questions linking the current text and accompanying representations to readers' prior knowledge. The control group did not receive any training to generate self-questions or to focus on linkages within the text or with prior knowledge. Otherwise the control group's training resembled that of the experimental groups, based on general reading strategies (e.g., highlight unclear terms, reread a paragraph when you don't understand, etc.) according to the literacy standards of Israel's Ministry of Education (Pedagogical Secretariat, State of Israel, 2009).

The dependent variable was scientific literacy on biology texts, comprising three skills: (a) identifying scientific phenomena, (b) generating scientific explanations, and (c) utilizing scientific evidence. Beyond collecting assessments of scientific literacy before initiating the 12-week study unit (baseline) and immediately after the unit's completion (to evaluate short-term effects), follow-up on long-term effects was conducted four months later at the end of the school year. Follow-up aimed to assess the possible lasting effects of the two learning approaches even after the fading of the self-questioning training, while students continued in their natural untrained science lesson environment (Crabtree et al., 2010; see Puntambekar and Hubscher, 2005 for a detailed review on the importance of assessing fading effects in experimental studies). Ninth graders were selected in line with Organisation for Economic Co-operation and Development [OECD] (2006, 2014, 2017) expectations for students of this age to possess these scientific literacy skills, as reflected on PISA tests (Organisation for Economic Co-operation and Development [OECD], 2003, 2006, 2016) conducted internationally in ninth grade. As far as we know, no previous studies have compared students' attempts to create elaboration linking questions versus their attempts to create bridging linking questions as a means for promoting scientific literacy and specifically for promoting success in solving international PISA tasks in middle-school science learning.

Despite the paucity of research on self-generated linking self-questions, based on findings regarding the beneficial effects of implementing externally generated self-questions into scientific text reading tasks (e.g., Greene et al., 2010; Kostons and Van Der Werf, 2015), we predicted that the students in the two experimental groups (Within-Text and Extra-Text) would outperform the control group on all scientific literacy measures after training. Regarding the two experimental groups' comparison, in line with previous research on the importance of prior knowledge for reading comprehension of scientific texts (e.g., Gunn, 2008; Kaberman and Dori, 2009; Berkeley et al., 2011; Moseley et al., 2016; Joseph and Ross, 2018), the Extra-Text (Elaboration) group was expected to achieve higher scientific literacy results than the Within-Text (Bridging) group.

MATERIALS AND METHODS

Participants

Participants were 193 ninth-grade students, 89 boys and 104 girls, with a mean age of 15 years (*SD* = 0.64) attending nine classrooms. The middle schools were similar on the following parameters: middle-class socioeconomic status as defined by the Israel Ministry of Education (Central Bureau of Statistics, 2006), and students' pretest science achievement levels. The five middle-school teachers who were involved in the study (3 female, 2

TABLE 1 | Sample (N = 193) distribution into study groups.

School	Students' *n*	Teacher	Group			Total groups per school
			Extra-Text	Within-Text	Control	
1	59	a		1		3
		b	2			
2	39	c		2		2
3	20	d	1			1
4	51	e			2	2
5	24	e			1	1

male; mean age: 33 years, SD = 0.82) all held an academic degree in science, were certified for teaching science in middle and high school, and had more than 7 years of experience in science teaching.

Prior to the beginning of the study, the five teachers who taught these nine classrooms were randomly assigned (from the science teachers in the selected schools) to the three research groups, with three classes per group. Thus, two teachers and 57 students were assigned to the Extra-Text group, two teachers and 61 students were assigned to the Within-Text group, and one teacher and 75 students were assigned to the control group. **Table 1** presents the distribution of classes, teachers, and students by study group. The 193 participants in this study were those students who completed all pretest, posttest, and follow-up assessments, out of the total number of students in the nine classrooms (N = 267).

The Intervention

As seen in **Table 2**, for all three groups, the 12-week study unit (Lessons 3–14) aiming to promote reading comprehension of scientific tasks was designed to correspond with the Israeli national ninth-grade science curriculum (Israel Ministry of Education, 2013) and with the PISA conceptual framework for scientific literacy (Organisation for Economic Co-operation and Development [OECD], 2014, 2017). The five scientific texts and accompanying tasks employed in the study unit for all three groups in the present study (i.e., "Cellular Phone," "Light Cigarettes," "Diabetes and Life Habits," "Height of Brothers," and "Marching and Drinking" – see **Table 2**) were suggested by the Israel Ministry of Education, as assignments for promoting scientific literacy (National Authority for Measurement and Evaluation in Education [RAMA], 2012). Throughout the training in all three groups, students and teachers utilized these five PISA-like texts and tasks. Each text comprised a reading passage describing an authentic science-related situation, accompanied by a visual-graphic representation (diagram, graph, or table). Each accompanying task comprised questions of the same type that appear in international PISA tests: open-constructed-response, closed-constructed-response, short-response, multiple-choice items, and complex multiple-choice items.

The intervention structure and components derived from cumulative research indicating that for students to succeed in posing high-order self-questions to regulate their reading comprehension, they require preplanned orderly guidance, gradual practice, and supportive encouragement (Moseley et al., 2016). Specifically, as detailed in **Table 2**, for all three groups, the lessons included four phases: (1) *explanation* of the importance of reading texts in general and scientific texts in particular; (2) repeated *demonstrations* (modeling) of how to read the five aforementioned scientific texts effectively and solve their accompanying scientific literacy tasks, using reading strategies (e.g., draw conclusions, hypothesize, raise diverse options for problem solving, isolate variables, represent information in different ways) that science teachers have been instructed to teach by the Israeli government (Pedagogical Secretariat, State of Israel, 2009); (3) *practice*, in pairs, for solving the tasks accompanying the five given texts, presented on printed worksheets; and (4) class *discussion* of pairs' solutions to tasks.

In the two experimental groups, additional evidence-based features were incorporated into the learning environment to help students learn to pose their assigned self-questions (Extra-Text or Within-Text), with the aim of promoting students' comprehension of the biology texts. In these two groups, the *demonstration* phase (Phase 2 above) was supplemented by teachers' *explanation* about the rationale for their assigned self-questioning method and *demonstration* of externally generated self-questions (e.g., Mevarech and Kramarski, 2003). In the *practice* phase (Phase 3 above), the teachers in these two experimental groups added pairs' *practice* of self-questioning generation (e.g., Michalsky, 2013). In the *discussion* phase (Phase 4 above), the teachers in these two experimental groups added class-wide *discussion* of self-questions (Mevarech and Kramarski, 2003; Michalsky, 2013).

In each of the two experimental groups (Extra-Text and Within-Text), instructions for posing the assigned self-questioning type were integrated into the students' printed biology task worksheets throughout the text. Students in these groups were helped by these instructions during practice and discussion. Sample instructions for posing an Extra-Text self-question included: "Write a question that refers to the connection between the ________ [results OR methods OR variables] of the research study that you just read and your prior knowledge about this issue." Sample instructions for posing a Within-Text self-question included: "Write a question that refers to the connection between the last paragraph that you read and _______ [the graph adjacent to the text OR one of the earlier paragraphs in the text]."

TABLE 2 | Summary of research design.

Lesson	Group	Element	Description	References
1–2 (Oct.)	All	*Pretests* for scientific literacy skills	Students complete 8 PISA tasks measuring baseline scores: "Semmelweis' Diary" – Items: 1, 2, 3, 4, 5, 6 "Tobacco Smoking" – Items: 1, 3	Organisation for Economic Co-operation and Development [OECD] (2006, 2007, 2009a,b)
3–11 (Oct. – Jan.)	All [NOTE THAT ADDITIONS FOR EXTRA-TEXT AND WITHIN-TEXT GROUPS ARE PRESENTED IN CAPS]	*Research process*	Lessons 3–4: Explanation and Demonstration. Teacher explains the importance of reading texts in general and scientific texts in particular. TEACHER EXPLAINS HOW TO CREATE AND ANSWER SELF-QUESTIONS (PER ASSIGNED EXTRA-TEXT OR WITHIN-TEXT GROUP) TO HELP UNDERSTAND SCIENCE TEXTS. Teacher demonstrates how to read and solve the "Cellular Phone" scientific literacy task using various reading skills (e.g., mark unclear words) according to Ministry of Education Department of Science Teaching guidelines (Pedagogical Secretariat, State of Israel, 2009) WHILE GENERATING SELF-QUESTIONS. Students observe the demonstration and participate in the task solution in the whole class. Lessons 5–6: Training in Pairs. Student pairs read the "Light Cigarettes" text and solve the task WHILE GENERATING AND ANSWERING EITHER EXTRA-TEXT OR WITHIN-TEXT QUESTIONS. Teacher moves among pairs and helps if difficulties arise. Lesson 7: Class Discussion. Teacher and whole class discuss pairs' solutions to the previous "Light Cigarettes" task, THE SELF-QUESTIONS THAT PAIRS POSED (EXTRA-TEXT OR WITHIN-TEXT), AND HOW THOSE QUESTIONS HELPED THEM SOLVE THE TASK. Lessons 8–9: Explanation and Demonstration. Similar to Lessons 3–4, using "Diabetes and Life Habits" scientific literacy task. Teacher explains and demonstrates again how to read and solve the task using reading skills according to Ministry of Education Department of Science Teaching guidelines, WHILE USING THE SELF-QUESTIONING PROCEDURE TO STRENGTHEN STUDENTS' TECHNIQUE AND ASSIST IN LOCATING DIFFICULTIES. Improvement from previous training in pairs is examined. Lessons 10–11: Training in Pairs. Similar to Lessons 5–6, using "Height of Brothers" task. Lesson 12: Class Discussion. Similar to Lesson 7, referring to "Height of Brothers" task. Lessons 13–14: Task Solution in Pairs and Class Discussion. Similar to Lessons 5–7, student pairs solve the "Marching and Drinking" task and then the class discusses pairs' task solutions AND SELF-QUESTIONS. Finally, teacher and class summarize and review the study unit on science text reading and task solution UTILIZING SELF-QUESTIONS.	Israel Ministry of Education (2010), National Authority for Measurement and Evaluation in Education [RAMA], 2010, 2012
15–16 (Feb.)	All	*Posttests* for scientific literacy skills	Students complete 8 PISA tasks measuring short-term effects: "Sunscreen" – Items: 2, 4a, 4b "Cloning" – Items: 1, 2 "Ultrasound" – Items: 2, 3 "Genetically Modified Crops" – Item: 2	Organisation for Economic Co-operation and Development [OECD] (2006, 2007, 2009a,b)
17–18 (June)	All	*Follow-up* on scientific literacy skills	Students complete 8 PISA tasks measuring long-term effects: "Evolution" – Item: 1 "Health Risk" – Item: 1 "Tobacco Smoking" – Item: 3 "Tooth Decay" – Item: 3 "Fit for Drinking" – Items: 3, 4 "Mary Montagu" – Items: 1, 2	Organisation for Economic Co-operation and Development [OECD] (2006, 2007, 2009a,b)

Students in the control group received the same study unit and they read and solved the same biology tasks as the other two groups, but without any training regarding self-questions for within-text or extra-text linkages. To ensure that the instruction methods were properly implemented as designed, all five classrooms were observed by the first author every 2 weeks for all four months of the experiment (5 lessons per week × 8 weeks = 40 observations altogether). Observations were conducted of every second lesson where the two self-generated linking self-questioning methods were implemented, and for one random weekly lesson in the control group. The first author, an expert in reading science texts, science literacy, and the differences between the two instructional conditions, met with each of the five teachers after each observation to give feedback, answer questions, and offer recommendations for improvement if necessary. In general, the teachers adhered well to the training they had received, both regarding the science learning unit and the training on reading scientific texts.

Teacher Training

To prevent treatment diffusion and compensatory rivalry, teachers underwent separate one-day training according to assigned study group and were masked to the other groups' study procedures. The two teachers assigned to the Extra-Text group were trained together, the two teachers assigned to the Within-Text group were trained together, and the one teacher assigned to the control group was trained alone. To ensure consistency, the same basic training program to impart the pedagogical content knowledge for the ninth-grade science curriculum (except for the addition of the self-questioning contents) was delivered to all teachers by the same instructor (first author).

Training initially introduced all teachers to the importance of enhancing students' scientific literacy and to the difficulties encountered in comprehending scientific texts. Next, all teachers received the rationales and techniques for the preplanned orderly guidance, gradual practice, and supportive encouragement (Moseley et al., 2016) that they would be implementing while teaching the 12-week study unit – comprising the explanation, demonstration/modeling, task solution, and class discussion procedures. Finally, all teachers observed the instructor as she modeled the assigned group's student training in a real ninth-grade classroom with students who did not participate in the study.

For the four teachers assigned to the two intervention groups, the instructor additionally discussed the importance of helping students pose their own linking questions to promote students' comprehension of scientific texts. The four teachers also observed the instructor as she modeled the student training in the assigned self-questioning type (Extra-Text/Within-Text) in the real ninth-grade classroom. The control group teacher received the relevant pedagogical content knowledge and observed the instructor's real-time in-class modeling without self-addressed questions.

Assessments

As seen in **Table 2**, students' scientific literacy was assessed at each of the three intervals (Lessons 1–2 at pretest, Lessons 15–16 at posttest, and Lessons 17–18 at follow-up). The tests at the three intervals were conducted under the same conditions in all groups, in the science classrooms at the school that the students attended, during morning hours, with the class teacher present to supervise independent testing performance. All groups received exactly the same tests, comprising a different set of PISA texts with eight accompanying test items at each interval (Organisation for Economic Co-operation and Development [OECD], 2006, 2007, 2009a,b). For example, at the baseline interval, students received two texts, Semmelweis' Diary with six test items and Tobacco Smoking with two test items (see **Table 2**). Each PISA text comprised a reading passage depicting an authentic science-related situation, accompanied by a visual-graphic representation. The eight PISA test items assessed at each interval covered the three main skills of scientific literacy: (a) phenomenon identification, (b) scientific explanation, and (c) evidence utilization.

PISA test items' comparability across the three intervals was maintained for item type (e.g., closed-constructed-response), item level [e.g., according Bloom's (1956) taxonomy of cognitive categories: knowing, understanding, evaluation, synthesis], and required literacy skill (e.g., phenomenon identification). For example, Semmelweis' Diary Item 3 at the pretest (Question 1.2, Organisation for Economic Co-operation and Development [OECD], 2009a) as well as Sunscreens Item 2 at the posttest (Question 8.2, Organisation for Economic Co-operation and Development [OECD], 2009a) and Tobacco Smoking Item 3 at the follow-up (Question 24.3, Organisation for Economic Co-operation and Development [OECD], 2009a) were all comparable multiple-choice closed items examining "phenomenon identification." Likewise, Semmelweis' Diary Item 1 at the pretest (Question 1.1, Organisation for Economic Co-operation and Development [OECD], 2009a) as well as Sunscreens Item 3 at the posttest (Question 8.4, Organisation for Economic Co-operation and Development [OECD], 2009a) and Evolution Item 1 at the follow-up (Question 28.1, Organisation for Economic Co-operation and Development [OECD], 2009a) were all comparable open items examining "evidence utilization."

The scoring procedure followed PISA scoring instructions. For open items, scoring was: 0 for incorrect/missing answer, 1 for partial answer, and 2 for a complete answer. For closed items, scoring was: 0 for incorrect/missing answer and 2 for correct answer. Reliability (Cronbach alpha) was 0.74 for the pretest, 0.67 for the posttest, and 0.71 for the follow-up.

Ethical Procedures

This study was reviewed and approved by our university's institutional review board and departmental ethics committee, in accordance with the ethical principles of the American Psychological Association. Parents provided written informed consent for their children to participate in this study, and the ninth graders provided their assent, as required by the Chief Scientist in the Israeli Ministry of Education.

RESULTS

Total Scientific Literacy

To examine students' scientific text reading comprehension growth under three instructional methods at the three time intervals, we first examined differences in total scores, using three one-way ANOVAs for each time separately (see **Figure 1**). No significant difference was found between the groups at the pretest, F (2,190) = 2.62, p = 0.076, η^2 = 0.03. However, at the posttest interval (Time 2), significant differences were found, F (2,190) = 24.39, p < 0.001, η^2 = 0.20 [*Levene's test of p-value* = 0.086, meeting the assumption of equality of variance].

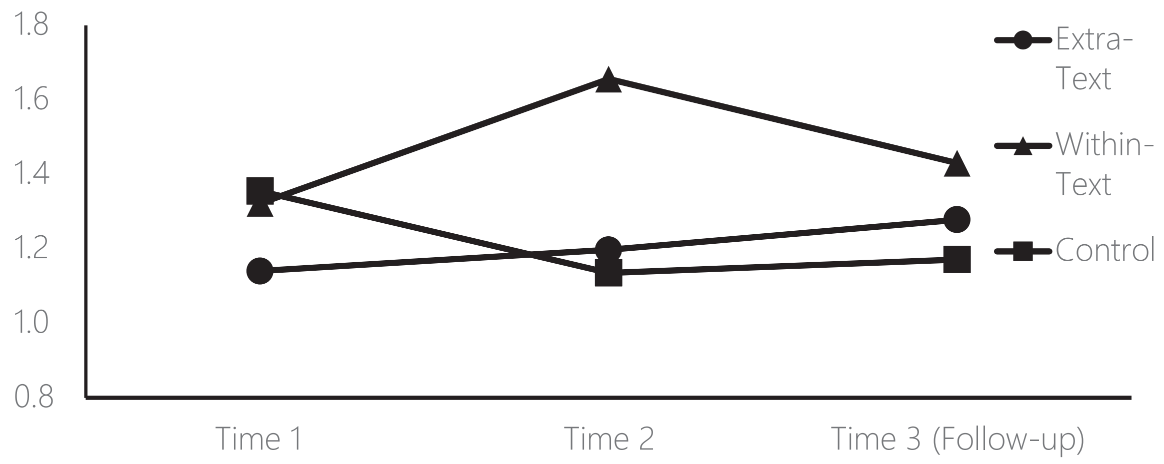

FIGURE 1 | Total scientific literacy at three intervals.

TABLE 3 | Means and standard deviationsfor scientific literacy scores at three intervals by study group.

Scientific literacy	Time interval		Group		
			Extra-Text (n = 57)	Within-Text (n = 61)	Control (n = 75)
Total	Pretest	M	1.14	1.32	1.35
		SD	0.61	0.44	0.60
	Posttest	*M*	1.20	1.65	1.13
		SD	0.46	0.38	0.51
	Follow-up	*M*	1.28	1.38	1.17
		SD	0.42	0.45	0.42
Components:					
Giving a	Pretest	*M*	1.32	1.42	1.41
scientific		*SD*	0.73	0.65	0.77
explanation	Posttest	*M*	1.34	1.72	1.26
		SD	0.62	0.52	0.68
Follow-up		*M*	1.38	1.65	1.13
		SD	0.60	0.50	0.56
Utilizing	Pretest	*M*	0.50	0.65	0.77
scientific		*SD*	0.85	0.88	0.88
evidence	Posttest	*M*	0.55	1.41	0.47
		SD	0.85	0.86	0.79
Follow-up		*M*	1.11	1.03	1.08
		SD	0.57	0.66	0.65
Identifying a	Pretest	*M*	1.40	1.80	1.81
scientific		*SD*	0.92	0.60	0.58
phenomenon	Posttest	*M*	1.55	1.77	1.54
		SD	0.83	0.64	0.79
	Follow-up	*M*	1.36	1.52	1.36
		SD	0.75	0.68	0.73

Scores ranged from 0 to 2.

Post hoc analysis (using Bonferroni) indicated that the Within-Text group significantly outperformed the other two groups after intervention, whereas no significant differences were found at posttest (Time 2) between the Extra-Text and control groups. At the follow-up interval (Time 3) four months after termination of intervention, some of the short-term effects were maintained in the long term, F (2,190) = 6.20, p = 0.002, η^2 = 0.06 [*Levene's test of p-value* = 0.931]. *Post hoc* analysis indicated that the Within-Text group continued to significantly outperform the control group on total scientific literacy scores but did not continue to outperform the Extra-Text group (p = 0.164) (see **Table 3** for means and standard deviations).

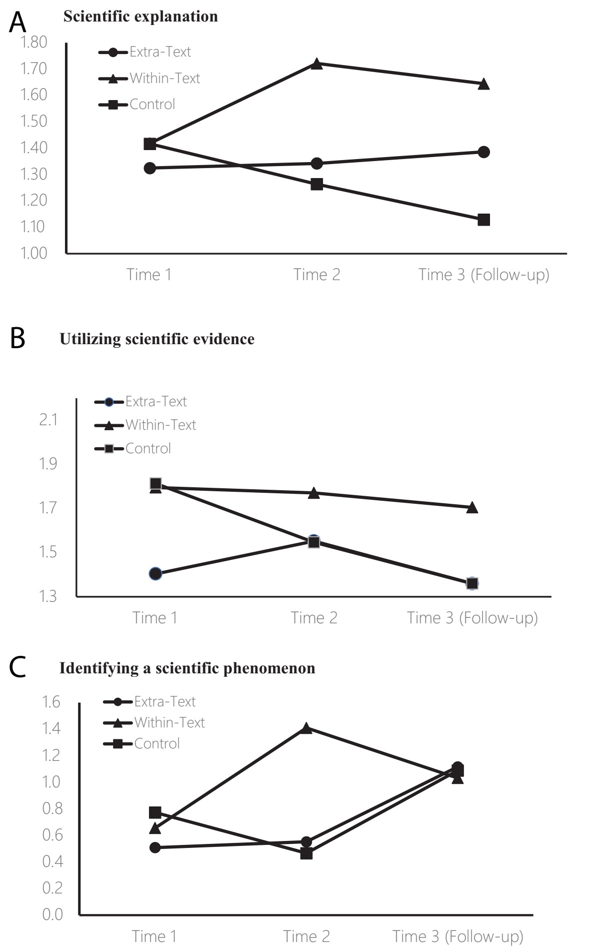

FIGURE 2 | Scientific literacy for the **(A)** scientific explanation, **(B)** evidence utilization, and **(C)** phenomenon identification components.

Scientific Literacy Components

In the next step of analysis, we examined differences between the three groups in each of the scientific literacy components separately, using a separate one-way MANOVA at each time interval, with the three components as dependent variables. At the pretest (Time 1), a significant difference emerged at the multivariate level, F (6,376) = 2.40, p = 0.027, η^2 = 0.04. Univariate tests (see **Figure 2A**) showed no significant inter-group differences on baseline scientific literacy for either scientific explanation, F (2,190) = 0.33, p = 0.718, η^2 = 0.003, or evidence utilization, F (2,190) = 1.50, p = 0.226, η^2 = 0.02. For the third component, scientific phenomenon identification, a significant difference was found at the pretest (Time 1), F (2,190) = 6.50, p = 0.002, η^2 = 0.06, with the Extra-Text group scoring significantly lower than the control group and the Within-Text group.

At the posttest (Time 2) interval, a significant inter-group differences was found at the multivariate level, F (6,376) = 9.60, $p < 0.001$, η^2 = 0.13 [*Box's M* = 12.61, p = 0.420, meeting the assumption that the variance-covariance matrices were equal across groups]. As seen in **Figure 2B**, for both of the scientific literacy components that had not shown significant inter-group differences at the pretest (Time 1) interval, a significant difference now emerged in the posttest univariate tests: scientific explanation, F (2,190) = 10.08, $p < 0.000$, η^2 = 0.10, and evidence utilization, F (2,190) = 24.96, $p < 0.000$, η^2 = 0.21. *Post hoc* analysis indicated that, for both of these components, the Within-Text group significantly outperformed the other two groups immediately after intervention. For the scientific phenomenon identification component that had shown significant pretest (Time 1) inter-group differences, no significant differences were found at the posttest (Time 2), F (2,190) = 1.76, p = 0.175, η^2 = 0.02.

At the follow-up interval (Time 3) 4 months after termination of intervention, some of the short-term effects were maintained in the long term [multivariate level F (6,376) = 6.52, $p < 0.001$, η^2 = 0.09; *Box's M* = 20.50, p = 0.067]. As seen in **Figure 2C**, a significant difference was found on the univariate test for the scientific explanation component, F (2,190) = 14.51, $p < 0.000$, η^2 = 0.13. *Post hoc* analysis indicated that, for this measure, the Within-Text group significantly outperformed the other two groups. However, the previous significant inter-group difference found at posttest (Time 2) for the evidence utilization component, favoring the Within-Text group, was not maintained four months later (Time 3), F (2,190) = 280.28, p = 0.760, η^2 = 0.003. Regarding scientific phenomenon identification, no significant inter-group differences emerged at the follow-up interval (Time 3), F (2,190) = 5.25, p = 0.06, η^2 = 0.05).

DISCUSSION

This study aimed to promote scientific literacy – now considered a major goal in science education worldwide (National Research Council of National Academies, 2011; Organisation for Economic Co-operation and Development [OECD], 2014, 2016, 2017; National Academies of Sciences, Engineering and Medicine, 2016). The major findings of the current study – examining the effects of ninth graders' attempts to generate different kinds of self-addressed linking questions while reading scientific texts – were twofold. First, as expected, students' reading of scientific texts while receiving support for generating either Extra-Text or Within-Text linking self-questions was more effective in developing scientific literacy growth than was reading of scientific texts without such self-questioning support (control group). Second, in contrast to our hypothesis, the students who were trained to generate self-questions about the connections between different parts of the task itself (Within-Text) achieved higher overall scientific literacy than those learners who received training to generate self-questions that connected the text to their prior knowledge (Extra-Text), with some long-term maintenance of these benefits. However, the current outcomes regarding the three main skills comprising scientific literacy (phenomenon identification, scientific explanation, and evidence utilization) may inform the different advantages demonstrated by the two self-questioning strategies in the short and long term.

The Benefits of Self-Questioning Support During Reading

The advantage found here for both experimental conditions over the control condition coincides with previous studies showing that mere exposure to scientific texts is insufficient, and that explicit instruction is required to train students to self-regulate their own reading (Cromley and Azevedo, 2007). As Hartman (in Schraw, 2001, p. 56) argued:

Teachers should not be satisfied with putting students in situations, which require them to use any strategy they want students to use. Practice isn't enough. It is also important to provide explicit instruction in **when, why and how** to use the strategy; students need to understand the rationale and effective procedures for the strategy so that they can recognize appropriate contexts for its use, so that they have criteria for evaluating their strategy, and so they can self-regulate its use. [bold is original].

Perhaps the very fact that students in the two experimental groups had to generate self-questions linked to their reading task in itself promoted students' self-regulated learning processes during reading comprehension, which in turn positively affected their science literacy achievements. Generating self-questioning has the potential to guide students to pay attention to specific aspects of their learning process (Chin and Brown, 2002; Michalsky et al., 2009), thereby helping students to monitor, regulate, and evaluate learning processes. Chin and Brown (2002) found that university students who closely followed self-questions often used these questions as a checklist for reexamining their reading processes and courses of action. Michalsky (2013) concluded that cognitive-metacognitive self-questioning is a self-regulation tool that helps high-school students (10th graders) to shift their attention from procedural thinking to regulation processing, including the construction of sub-goals, the monitoring of learning, and the evaluation of solutions.

The Benefits of Linking Within the Text Over Linking to Prior Knowledge During Reading

Students in the Within-Text group reached the highest achievements of all groups for total science literacy scores and for two of its three components (utilizing scientific evidence and generating scientific explanations) immediately following the intervention. This advantage of the bridging self-questioning strategy that supported students to make connections within the task – over the self-questioning strategy that supported students to "elaborate" by making connections to prior knowledge and also over the control group's lack of self-questions – may involve characteristics of these two science skills. Previous studies have pointed out bridging skills (e.g., McNamara, 2004, 2011, 2017; Kuo and Anderson, 2006) and skills for connecting to prior knowledge (e.g., Greene et al., 2010; Kostons and Van Der Werf, 2015) but did not analyze them together. The abilities to locate and use scientific evidence and to offer explanations for scientific occurrences require understanding and reasoning by means of data, facts, and complex multifaceted explications – which often appear in different places in the given text and in its accompanying visual-graphic representations. Thus, practice in posing self-questions to find and understand those connections between the different parts of a science task can assist learners to locate the relevant evidence and put together different pieces of given information to deepen integrative comprehension of complex scientific processes. Kozma et al. (2000) as well as McNamara (2017) argued that the ability to link different parts of the task – such as establishing relationships between paragraphs, sentences in the text, and accompanying graphs, tables, or diagrams – helps the learner to understand the processes and the ideas that appear in the text.

To generate a logical explanatory process, students must find the connections between various ideas and concepts, which was the focus of the self-addressed questioning support received in the Within-Text group. It seems that the ability to formulate scientific explanations relies primarily on various information bits distributed throughout the given task and is probably the least dependent on prior knowledge. Another possibility is that ninth-grade students may have knowledge gaps regarding the scientific topics appearing in these given reading tasks, which may hinder their ability to formulate effective self-questions for activating relevant scientific knowledge (Gunn, 2008; Joseph and Ross, 2018).

Interestingly, regarding the third component of scientific literacy, identifying scientific phenomena, only students in the Extra-Text group demonstrated significant improvement immediately after the intervention. To be noted, these students had shown lower scores than their peers in the other two groups at baseline but caught up after training and even maintained those gains four months later (see below). This finding may be due to the fact that the ability to recognize a scientific process, body, or event requires learners to recall some existing general knowledge on the topic at hand, which was the focus of the self-addressed questioning support received in the Extra-Text group. Additional studies have also mentioned the impact of prior knowledge on understanding scientific texts (e.g., Greene and Azevedo, 2009; Greene et al., 2010; Kostons and Van Der Werf, 2015). In contrast, practicing the generation of connections between the information bits appearing within the science task itself (the Within-Text group) did not appear to offer the extra knowledge needed to identify the wider scientific phenomena being discussed in these biology tasks.

However, the current outcomes indicating that the elaboration (Extra-Text) strategy was not particularly effective overall for promoting science reading comprehension deserve some reconsideration. Different research studies have emphasized that learners' disciplinary and prior knowledge can critically influence the absorption, processing, understanding, and learning of new information (Greene et al., 2010; Kostons and Van Der Werf, 2015). Yet, perhaps simply asking students to make connections to prior knowledge was an overly general training method because it targeted unfocused non-specific knowledge. This lack of focus may be speculated as having possibly led to students' cognitive overload, a thought-scattering effect, or repeated searching loops, which may have hindered their ability to find the relevant prior knowledge or to link it appropriately to the given biology task. Researchers have noted the disadvantage of posing questions that lack focus (Davis, 2003; Van den Broek et al., 2006).

Long-Term Skill Maintenance

In line with recommendations to examine maintenance of intervention gains (Puntambekar and Hubscher, 2005), this study followed up on students' long-term achievements in scientific literacy four months after the intervention. At the follow-up interval, the achievements of the Within-Text group remained higher than those of the control group both on the total scientific literacy score and on the scientific explanation component. On the scientific explanation component, the achievements of this group were also higher than those of the extra-text group. However, the students in the Within-Text group were unable to maintain the improvement they had achieved immediately after the intervention in their ability to utilize scientific evidence. In this component of scientific literacy, no differences between the groups were found. Perhaps the ability to use scientific evidence may require longer training in order to maintain the gains achieved at the end of the intervention, possibly because this skill is knowledge-specific and therefore relies on memory retention of scientific facts (Kostons and Van Der Werf, 2015; McNamara, 2017).

In the long term, the Extra-Text group no longer showed an advantage over the control group over the control group on the total scientific literacy score or on the other components; however, they were able to maintain the improvement they had achieved immediately after the intervention in their ability to identify scientific phenomena. As mentioned above, this group's ability to identify scientific phenomena was lower than that of the other groups prior to the training; hence, it can be said that the support they received during intervention to elaborate by seeking relevant prior knowledge outside the text itself was a strategy that continued to significantly help them while reading scientific texts later, after the training supports were withdrawn. Inasmuch as the ability to identify a scientific occurrence always relies on something that students know, it appears that their new ability to ask themselves questions about their own prior knowledge helped them to reach these higher achievements in line with many studies highlighting the importance of prior knowledge (e.g., Kostons and Van Der Werf, 2015; Willis et al., 2019).

Practical Implications, Future Research, and Limitations

The present findings suggest practical implications for scientific literacy growth programs targeting middle-school students. The Organisation for Economic Co-operation and Development [OECD] (2017) underscored the challenge facing science educators to develop pedagogical models that engage students in authentic, deep forms of inquiry, which promote scientific literacy and thinking as well as metacognition skills and behaviors while reading science texts (McNamara, 2007; Kostons and Van Der Werf, 2015). The current outcomes imply that such programs for middle-school students should focus on the two key elements found here to influence students' scientific literacy growth: empowering students' elaboration and bridging types of self-generated linking questions.

The findings of the present study can make a theoretical contribution to the extant research on different types of metacognitive reading strategies and their impact on literacy in general and scientific literacy in particular. Previous studies have pointed to the importance of creating self-questions (Kaberman and Dori, 2009; Moseley et al., 2016; Joseph and Ross, 2018) as well as the importance of making different connections while reading scientific texts (McNamara, 2017). This study combines these two strategies and highlights the unique value of creating self-directed linking questions of different types (extra-text, within-text) for scientific literacy and of its components: (a) phenomenon identification, (b) scientific explanation, and (c) evidence utilization.

Importantly, the current training program and assessments derived directly from the Organisation for Economic Co-operation and Development [OECD] (2017) model for international PISA scientific literacy testing; therefore, this study contributes explicitly to the understanding of which skills can help promote each of the globally recommended literacy components. For example, middle-school students' ability to utilize scientific evidence and generate scientific explanations are mainly assisted by self-creation of questions that link parts within the text and task, whereas the ability to identify scientific phenomena is mainly influenced by creating self-directed questions that help the student make links outside the text, to prior knowledge. These findings offer practical implications for implementing methods based on metacognitive strategies (Herscovitz et al., 2012) to help students understand scientific texts and even to achieve higher scores on international tests. Hence, this research is also extremely important in terms of its applied contribution and can highlight the need for teacher intervention through different reading strategies and especially through asking different types of linking questions that lead the student to understand scientific texts and success in using different scientific literacy skills.

Another contribution of this study is its follow-up on the effects of metacognitive intervention in the long term, months after training has been terminated. Previous studies (e.g., O'Day and Smith, 2016) have underscored the difficulty in maintaining outcomes over time from interventions that engage students in different reading strategies. The current study likewise found that some gains did not remain, but, in some situations, they were maintained. Future research should continue to delve into possible factors promoting maintenance of scientific reading strategies.

Although implementation of the self-generated linking questions model in middle-school classrooms rendered beneficial effects on students' scientific literacy, several additional questions remain, both at the theoretical and practical levels. First, it would be interesting in future research to assess this two-approach model for literacy in other content domains like mathematics, chemistry, and physics. Second, recently, the National Research Council of National Academies (2011) published a new framework (*A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*) that explicitly underscores the need for science teaching as a practice. Practice in this context refers to a way of learning from doing and not (just) from reading and talking science. It would be interesting for future researchers to go beyond mere reading of scientific texts to assess the effects of self-generated linking questions on active science learning through doing, as recommended by these new calls for reform.

As mentioned, a strength of this study is its examination of the intervention's effectiveness using international PISA tests, which have high validity and reliability (Organisation for Economic Co-operation and Development [OECD], 2006, 2007, 2009a,b). However, it is worthwhile in the future to complement quantitative PISA-based assessments with qualitative methods such as student interviews to shed light on the two intervention groups' learning experiences as related to the differences in their assessment outcomes. In addition, future research using qualitative methods may compare how text difficulty, domain familiarity, and prior knowledge may affect the way students utilize self-generated linking question instruction as provided while reading scientific texts. Furthermore, to comprehensively scrutinize the issues at hand, researchers would do well to extend investigation to younger students, examine gender differences, and determine teachers' own skills for self-generating linking questions as playing a possible role in their ability to develop these capabilities among their students (Willis et al., 2019).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the research reported in this study involving human participants was approved by the Research Ethics Board at Bar-Ilan University. According the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

TM performed the research design, developed the coding schemes, and supervised the study. HS helped with the data collection and the coding. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Education

ORIGINAL RESEARCH
published: 04 March 2021
doi: 10.3389/feduc.2021.604791

An Exploratory Study Interrelating Emotion, Self-Efficacy and Multiple Intelligence of Prospective Science Teachers

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This research offers a descriptive and inferential analysis of the emotions toward the teaching of science felt by 144 second-year students of a Primary Education bachelor's degree course, identifying their learning styles in accordance with the theory of Multiple Intelligences, studying their perception of self-efficacy concerning the different scientific contents they would need to teach, and establishing correlations between these variables. The investigation is quantitative in character, carried out via a survey, using SPSS and JASP for the data analysis. The results show that these prospective teachers feel greater rejection toward Physics and Chemistry than toward Biology and Geology (they mainly express enthusiasm for the latter). It is possible to establish differences in the emotions that the prospective teachers feel toward science depending on which path they took in their pre-university studies (Arts or Sciences). There are correlations between feeling positive emotions and having greater self-efficacy in teaching those same scientific topics. Those who feel negative emotions, such as fear or rejection, toward Physics and Chemistry have lower self-efficacy. There are correlations between having greater self-efficacy when teaching science and having a predominantly logical-mathematical intelligence. There is also a relationship between having a predominantly logical-mathematical type of intelligence and feeling more positive emotions toward sciences. Predictors of emotional dimension and self-efficacy have been also explored by multiple regression.

Keywords: emotions, multiple intelligences, self-efficacy, affective domain, prospective teachers

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Education

Received: *10 September 2020*
Accepted: *25 January 2021*
Published: *04 March 2021*

Citation:
Hernández-Barco M, Cañada-Cañada F, Corbacho-Cuello I and Sánchez-Martín J (2021) An Exploratory Study Interrelating Emotion, Self-Efficacy and Multiple Intelligence of Prospective Science Teachers. Front. Educ. 6:604791. doi: 10.3389/feduc.2021.604791

INTRODUCTION

The link between emotions and learning is inescapable: educational processes are replete with affect (Garritz, 2009). There is still much room for progress, however, in analyzing together the affective and cognitive dimensions at whichever educational level (pre-primary, primary, secondary, or higher education). The world we live in, with its constant scientific and technological progress, requires a redesign of how science is taught, and reflection on the kind of science education that society needs–science capable of contributing to social progress and the integral development of society (Mellado et al., 2014; Sanchez-Martin et al., 2018).

What we find, however, is that on many occasions students decide not to continue their higher education in science, often because of the emotional rejection that some scientific subjects generate, generally related to experiences they have lived through in the school classroom (Vázquez and

Manassero, 2008; Mellado et al., 2014). Secondary students' career aspirations in STEM fields have been analyzed, and a gender gap was brought to light. Science subjects at school constitute a major obstacle for young women's aspirations, and the gender stereotype of maths and science persist (Eccles, 2009; Makarova et al., 2019). Pupil's gender differences in science achievement, and in subsequent occupational choices, might be explained by stereotypical teachers beliefs (Tiedemann, 2000).

Pekrun and Stephens (2010) have investigated that the emotional dimension is extremely powerful and affects to other personal aspects as motivation, concentration or the interest that we have on the project what we are working on. Many factors also influence the emotional dimension, as gender or self-efficacy, which they refer to as achievement-related beliefs. This is particularly relevant in prospective teachers, due to the effects that these aspects could have on control perception and tasks development in their future job. Therefore, emotions, self-efficacy and multiple intelligences of a prospective teachers' sample have been described and analyzed in this paper. Prospective teachers use to feel negative emotions toward sciences (as anxiety, boredom or rejection) (Dávila-Acedo et al., 2015) and they also present a low self-efficacy perception, feeling insecure when teaching science contents (Brígido et al., 2012).

For this reason, it is necessary to have scientifically and emotionally competent teachers in order to improve pupils' emotional experiences and the quality of education, which allows science teaching to take pupils' affective dimension into account, and to distance itself from the traditional roles of expository teaching by combining current knowledge of neuroeducation and psychology. This is possible by following Gardner's theory of Multiple Intelligences (Sanchez-Martin et al., 2017). This concern led to the setting of this research study being directly undertaken with prospective primary teachers. Spanish University teaching and all the curricula have been changed due to the Bologna Process and the European Higher Education Area. In Spain, initial primary teacher education is a four-year Bachelor's Degree course of Primary Education Teacher. These students are trained to be teachers at Primary Education level (children aged 6–12 years) and therefore, they will teach sciences at primary school. During their time as primary school pupil themselves, prospective primary teachers were taught science as a single subject (namely, Natural Sciences) during their primary school period. At the compulsory secondary education (12–16 years old) they were taught science also as a single subject of each of the first two years and then, in the third year sciences subject was splitted into two science subjects - Biology and Geology, and Physics and Chemistry-. In the fourth year, science subjects become optional. Finally, during upper secondary education (16–18 years old), the students had a choice of one of two modalities: either Humanities, Social Sciences, and Arts, or Science, Health, and Technology path. Usually, prospective primary teachers choose the first path. This work is characterized as being non-experimental causal or correlation study, an exploratory descriptive analysis of the sample is presented. Information was collected for three variables that were taken into account for the subsequent development of research objectives: emotions, self-efficacy, and multiple intelligences. To carry out this study, we set as a general objective to establish and analyze the possible relationships between emotions, self-efficacy, and the multiple intelligences of the students in the second year of the Primary Education Degree at the University of Extremadura. This general objective can be split into four specific objectives:

Specific Objective 1: To analyze, in a descriptive way, the emotions prospective teachers feel when facing the different scientific contents in their course. Distinguishing according to gender and to upper-secondary education path.

Specific Objective 2: To analyze, in a descriptive way, the self-efficacy of prospective teachers toward the different scientific fields, and to establish relationships between their perception of self-efficacy and the emotions they feel toward the different contents. Distinguishing according to gender and to upper-secondary education path.

Specific Objective 3: To define the profile of the students according to the theory of multiple intelligences.

Specific Objective 4: To establish correlations and looking for the predictor variables between the different intelligence profiles of the prospective teachers and the emotions and perceived self-efficacy they have toward the different scientific fields.

Emotions in Teaching and Learning

The emotions and the cognitive part have almost always been considered to be independent, with the cognition part encompassing aspects related to memory, learning, or attention, and the emotional part, motor and physiological responses and sentimental experience (Phelps, 2006). Nowadays, the association between the affective and cognitive dimensions in human beings is undeniable (Pessoa, 2008). Emotions influence pupils' learning results (Carmona-Halty et al., 2019) as they help to direct attention, which is a requirement for learning (Phelps, 2006). Events associated with emotions are easier to recall and last longer in one's memory (Mora, 2016). But the study of emotions, their application in the classroom, and the need for the existence of a good classroom climate for a beneficial, motivating and interesting educational process has not been sufficiently studied (Garritz, 2009), despite the need for teachers to carry out good emotional management and to possess strategies for resolving conflicts (Bonilla et al., 2020). What we know today is that teachers with high levels of stress reported also higher levels of anxiety and depression and that may also influence the student's affective experience in learning (Poon et al., 2019) but also a positive association between teachers and students positive emotions have been found in science lessons (Frenzel et al., 2009).

The key to begin generating changes in the practice of teaching may be to know how to activate emotions in the classroom, and to take advantage of current knowledge about the brain. This is especially important for the science classroom, given the current problem of pupil's alienation from scientific studies (Vázquez and Manassero, 2008). Such changes can be framed within the constructivist paradigm so as to lead to more meaningful learning (Ross, 2006; Krahenbuhl, 2016). In the context of this research, we use the definition of emotion proposed by Bisquerra (2003):

> Emotion is a complex state of an organism characterized by an excitation or perturbation that predisposes to an organized response. Emotions are generated in response to an external or internal event (Bisquerra, 2003, p. 12).

Recognizing and identifying pupils' emotions in the science classroom is the first step to be able to intervene. It is possible to find numerous classifications and taxonomies of emotions in the literature. Paul Ekman (1992) determines six emotions as basic: anger, disgust, fear, happiness, sadness, and surprise. Damásio (1994) classifies them into universal, background, and social. Goleman (1995) and Bisquerra (2003) are other authors who have tried to establish classifications of emotions. However, there is still no established categorization, and the choice of a reduced number of basic emotions on which every author can agree is quite a complex task (Mohammed, 2017). The emotions taken into consideration were classified as in Dávila-Acedo et al. (2015), based on that proposed by Fernández-Abascal et al. (2001).

Emotions impact student's learning and achievement (Frenzel et al., 2007). Differences by gender have been reported previously in achievement emotions in the domain of sciences, where girls reported significantly less enjoyment and pride than boys but more anxiety, hopelessness and shame due to the girls' low competence beliefs (Frenzel et al., 2007). It is necessary that both, in-service and prospective teachers, are aware of their own emotions and of what effects these may generate through their classroom activity, especially in those areas, such as Physics and Chemistry, that provoke negative emotions (Dávila-Acedo et al., 2015). The challenge is to create stronger positive emotions capable of counteracting the negative ones that condition and impede beneficial, motivating, and enthusiastic learning.

Prospective Teachers' Self-Efficacy

Self-efficacy is the term proposed by Bandura (1997) to define the belief in one's own abilities to organize and execute the actions necessary to reach certain achievements. Self-efficacy influences how we feel, think, and act. This is also related to many other dimensions, which include intentionality, self-regulation, and the reflection that allows us to control situations and has a great impact on our actions and decisions (Code, 2020). Eccles and Wigfield (2002) reflect about other psychological aspects, in addition to self-efficacy, as motivational beliefs, values and goals which are inexorable linking to the emotional dimension of prospective teachers. The authors perform a deep reflection about intrinsic motivation theories, and the necessity of pupils to believe that they are academically competent to improve their self-worth.

Self-efficacy is a predictor of the academic success and that is the consequence of the confidence and the students' beliefs that they are skilled of carried out their task (Putwain et al., 2013). Teachers and their behavior have an important impact in the academic goals of their students (Eccles and Wigfield, 2002). Children's perception of their control over results depends on how kindly and helpfully teachers are with them. The investigations of Yeager and Dweck (2012) concluded that students who believe (or are taught) in a growing mindset -what means that intellectual abilities are qualities that can be developed-lean toward showing higher attainment. Their suggestion is not to congratulate students for their own qualities, but to offer them the vision that they can overcome the challenges because they have the potential to change. Children need patience, but they will have help from teachers, family and colleagues, that's the way to prepare students to make them ready to deal with the problems resiliently.

Prospective teachers' self-efficacy has been shown to be a factor that predicts the behavior these teachers will have in their classrooms, and is related to the creation of a good classroom climate and good management of the class (Künsting et al., 2016). Self-efficacy is linked to the interest and performance while a task is being carried out (Nuutila et al., 2020). Those teachers with a greater sense of self-efficacy are less averse to taking risks in methods since they feel more comfortable in teaching the content (Borrachero et al., 2013). The study of prospective teachers' self-efficacy when teaching science is of especial relevance, since teachers tend in general not to feel confident when teaching science, and consider it particularly difficult to learn (Menon and Sadler, 2016). Literature review indicates that prospective teachers have a low self-efficacy for teaching sciences, and that is preceded by high levels of negative emotions (Brígido et al., 2012). Knowledge of the matter and mastery of the topic are necessary to be able to feel effective and to carry out this task. It is impossible for a teacher to be able to teach something they do not know–they need to understand the content and know how to teach it (Mellado et al., 2014). This is essential in science education because teachers should follow active methods in offering the approach to the content and the development of skills, methods distanced from teaching based on textbooks and abuse of theory.

Multiple Intelligences

A possible link between the above variables of our study (emotions and self-efficacy), which combine the two dimensions of affect and cognition, can be found in Gardner's theory of Multiple Intelligences (2011). Gardner suggests that people are not equal, but that each person has a different learning style and way of assimilating information (strongly influenced by their own individual preferences). He creates the model of multiple intelligences which has aroused so much interest and controversy (Shearer and Karanian, 2017). He opposes the way intelligence has traditionally been assessed with the use of the IQ test. In his studies, Gardner concludes that the human mind has a range of skills and abilities, and defines intelligence as a bio-psychological potential that could be induced by experience, culture, and motivational factors and defines the nine basic intelligences: musical, bodily-kinesthetic, logical-mathematical, spatial, linguistic, spiritual, interpersonal, intrapersonal, and naturalist (Mahasneh, 2013). Neuroscientific evidence reinforces the validity if MI theory (Shearer, 2018). It is important to note that people do not have a single intelligence profile, but rather better match one style or another which some authors have spoken of as "prevalent intelligence" (Sanchez-Martin et al., 2017).

The Gardner's theory inclusion in the classroom changes the methodology we teach and evaluate, since intelligence becomes the ability capable to provide solutions for different problems. Moreover, Gardner argued that there is no hierarchy, consequently none of the intelligences is more important than the others (Mahasneh, 2013). According to Yaghoob and Hossein (2016) academic achievement of secondary students is correlated with their multiple intelligences. The key is to provide the information of the topics in the way that students most like, taking advantage of cognition and emotion are interrelated (Immordino-Yang and Damasio, 2011).

The perspective from which this research is undertaken proposes adapting instructional strategies to the different intelligences found in the classroom, so that a response could be given to the heterogeneity of pupils and in order to foster meaningful science learning. This would be sustained by positive changes at an emotional and motivational level, recognizing the different identity of each pupil. The emotional effectiveness of multiple intelligences based teaching strategy in science lessons have been studied (Winarti et al., 2019) and proved that to design the classes according to their interest improve their motivation (Madkour and Mohamed, 2016).

MATERIALS AND METHODS

Participants

Our sample consisted of a total of 144 white Caucasian prospective primary teachers (53 men and 91 women, mean age 20.61, SD = 3.38), all enrolled in a Science Education subject (namely, Didactics of Matter and Energy) in the fourth semester of the Primary Education bachelor's degree (eight semesters in total) in the University of Extremadura's Education Faculty. Regarding their background studies, 75% of the sample (39 men and 69 women) had studied a modality of Humanities, Social Sciences, or Arts in upper secondary education (SS), and 25% of them (14 men and 22 women) a Science, Health, or Technology (SHT) path to access university studies. This sample was chosen conveniently, not randomly, from the population of prospective primary teachers who voluntarily answered a questionnaire about their emotions toward the sciences, self-efficacy, and multiple intelligences. Before being given the questionnaire, the students were informed about the goals of the research, its duration, procedure, and the anonymity of their data. All the participants provided their verbal informed consent prior to data collection. Researchers were always present during the implementation of the survey.

Measures

Design of the Questionnaire

For the data collection, we decided to draft a questionnaire about emotions, self-efficacy, and multiple intelligences (**Supplementary Appendix SA**). The students were asked to complete basic information about demographic aspects such as gender, age, and upper secondary education.

Regarding the prospective teachers' self-efficacy, a ten-point Likert-type questionnaire was used. A list of the most relevant scientific contents related to Physics and Chemistry and Biology and Geology, based on Primary Education curriculum, were included. For each content, prospective teachers were asked to measure their confidence for teaching it by a 1–10 scale, where 1 meant not prepared for teaching, and 10, quite comfortable for teaching.

In order to assess prospective teachers' emotions toward sciences contents, a survey-based study was conducted. For this, a prose-design questionnaire based on previous studies conducted by our research group was considered (Brígido et al., 2012; Borrachero et al., 2014; Dávila-Acedo et al., 2015; Jeong et al., 2019). The emotions were sorted into two groups, namely positive and negative emotions. Positive emotions included joy, confidence, fun, enthusiasm, satisfaction and surprise; while the negative ones were anxiety, boredom, fear, nervousness, rejection and worry. The students indicated which emotions were suggested by the propose science contents. These contents corresponded to those in Part I of the questionnaire in order to establish correlations between emotions and self-efficacy.

With regard to the multiple intelligences, a self-evaluation test extracted from Rosiña et al. (2020) was used, the questionnaire followed a five-point Likert scale (from strongly disagree to strongly agree). The test was consisted in 41 statements (7 for each multiple intelligence) what measure the multiple intelligences proposed by Howard Gardner (2011). The Cronbach's alpha value found out for different intelligences, logical-mathematical $\alpha = 0.719$, verbal-linguistic $\alpha = 0.715$, naturalistic $\alpha = 0.814$, musical $\alpha = 0.818$, bodily-kinesthetic $\alpha = 0.602$ (only 6 statements), visual $\alpha = 0.717$.

Validation of the Questionnaire, Data Collection, and Analysis

The questionnaire was validated by experts in Experimental Sciences Education, who read, modified, and approved it. It was passed to some students who give us the feedback and then final version was constructed. The questionnaire was in Spanish. The value of Cronbach's alpha allowed us to know the internal consistency of the different parts of the questionnaire. The obtained values enabled a grouping of the scientific content blocks into categories: Physics and Chemistry ($\alpha = 0.907$), and Biology and Geology ($\alpha = 0.942$). Regarding to the emotions, the Cronbach's alpha test was again applied, which supported to group the emotions into positive ($\alpha = 0.864$) and negative ($\alpha = 0.942$).

After preparing the questionnaire and selecting the sample, the questionnaire was given to all participants in a paper format in a regular class where they were voluntarily asked to complete them. After data collection, they were processed and transferred to a digital support for being statistically analyzed using the statistical package SPSS (Statistical Package for the Social Science) 22.0 (SPSS, 2017), and graphic descriptively analyzed (the sociodemographic variables frequencies, percentages, means, standard deviations) using Excel (2013) and JASP (V.0.11.1).

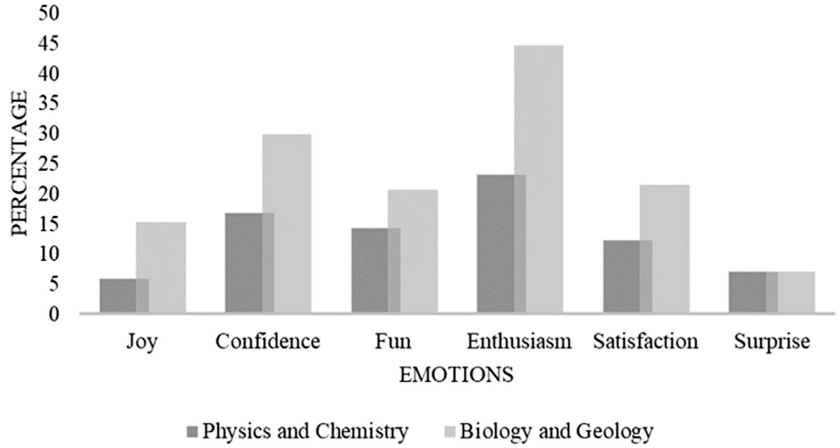

FIGURE 1 | Percentage of positive emotions toward science expressed by the prospective teachers.

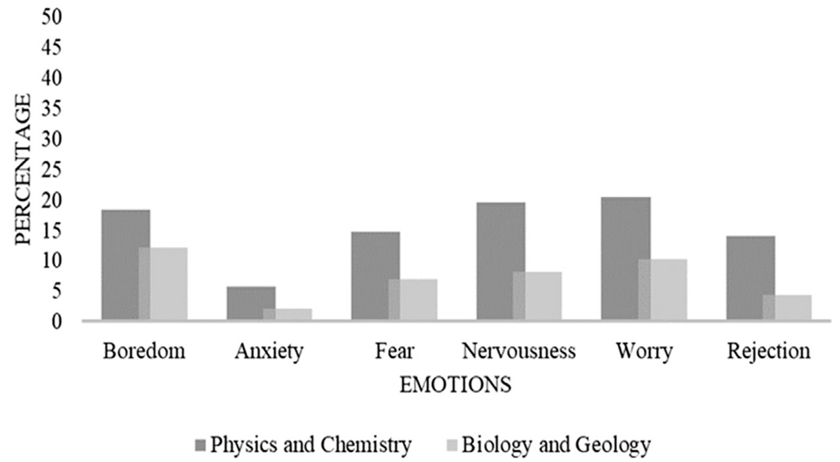

FIGURE 2 | Percentage of negative emotions toward science expressed by the prospective teachers.

The self-efficacy and MI data were averaged, and that data were used to establish differences by gender and by their upper secondary education. Both descriptive and non-parametric statistical test were performed to analyze the data. The use of non-parametric test was considered appropriate after checking normality, skewness and kurtosis of the individual variables. To find if there were significant differences by gender and their upper secondary education, we applied Mann-Whitney *U*-test. To explore relationships between emotions, self-efficacy, and multiple intelligences Spearman's correlations were applied. Bivariate correlations are limited in their usefulness for field studies such as this where many factors may be operating consecutively. Therefore, we also employed multiple regression to describe what variables (gender, secondary school track, intelligence type) best predict prospective teachers' positive and negative emotions toward sciences and their self-efficacy.

RESULTS

Objective 1. Prospective Teachers' Emotions Toward Science

With regard to the first objective of the study (descriptive analysis of the emotions prospective teachers feel when facing the different scientific contents) **Figure 1** shows that for Biology and Geology they indicate a higher percentage of positive (76.05%) than negative (23.95%) emotions. This is not the case for Physics and Chemistry, where they indicate feeling more negative (54%) than positive (46%) emotions.

After a detailed study of emotions, as shown in **Figure 1**, the most indicate emotion by the prospective teachers in both cases was enthusiasm, followed by confidence and satisfaction in the case of Biology and Geology, and fun in the case of Physics and Chemistry.

TABLE 1 | Mann-Whitney *U*-test *p*-values for gender differences in negative and positive emotions toward science.

Scientific field	Positive emotions	Rank-biserial correlation	Negative emotions	Rank-biserial correlation
Physics and Chemistry	<0.001	0.412	<0.001	−0.339
Biology and Geology	0.034	0.212	0.517	−0.065

With regard to negative emotions (**Figure 2**), it can be seen that the percentages indicated are substantially lower in the case of Biology and Geology. The prospective teachers report feeling mostly the negative emotions of worry, nervousness, and boredom.

There were gender differences in emotions, with men having higher percentage of positive emotions in both Physics and Chemistry (mean: 16.7%, SD = 9.1 for men and mean: 11.1%, SD = 10.2 for women) and Biology and Geology (mean: 24.4%, SD = 13.1 for mem and mean: 21.7%, SD = 15.4 for women). Female participants report feeling more negative emotions for Physics and Chemistry (mean: 17.9%, SD:14.4; vs. mean: 11.3%, SD = 9.0) and for Biology and Geology (mean: 7.5%, SD = 5.8 vs. mean: 6.9%, SD = 6.1). To determine whether these differences in positive and negative emotions were significant, Mann-Whitney *U*-test was applied. The *p*-values are given in **Table 1**. The statistical analysis results were contrasted with an $\alpha = 0.5$ (confidence *p*-value of 0.05).

With these results it is possible to conclude that women feel more negative emotions toward Physics/Chemistry (*p*-value = 0.001) and Biology/Geology (*p*-value = 0.034) and less positive emotions toward Physics/Chemistry (*p*-value = 0.001) than men, but that these differences are not significant for negative emotions toward Biology/Geology. Rank-biserial correlation can be considered as effect size and it is interpreted as r of Spearman's correlation, so r = 0.412 and r = −0.339 are a medium size effect for positive and negative emotions toward Physics and Chemistry.

In terms of the upper-secondary education path, no differences are found neither in the emotions toward Biology/Geology nor toward in Physics/Chemistry.

Objective 2. Prospective Teachers' Scientific Self-Efficacy

To determine whether there is any correlation between self-efficacy and the emotions, Spearman's correlations were used, and the results showed the existence of significant correlations between feeling positive emotions and having a high perception of self-efficacy (Spearman's rho = 0.339, *p*-value < 0.01). Furthermore, inverse and significant correlations were obtained between negative emotions and self-efficacy, i.e., feeling more negative emotions toward science is related to having a lower perception of self-efficacy (Spearman's rho = −0.255, *p*-value < 0.01).

Mann-Whitney *U*-test was applied to determine whether differences in terms of gender differences by self-efficacy were significant. We obtain that the mean value of self-efficacy is higher in men (mean = 5.2, SD = 1.8) than in women (mean = 5.0, SD = 1.8) teaching contents related to Physics and Chemistry and also teaching Biology and Geology (mean = 5.3, SD = 1.8 for men and mean = 5.1, SD = 1.8 for women). However, the data obtained show that gender does not influence self-efficacy when teaching scientific content.

In terms of the upper-secondary education path, students who had completed SHT upper-secondary education showed greater self-efficacy when teaching any scientific content. The biggest differences were found in self-efficacy shown when teaching contents related to Physics and Chemistry (mean = 6.2, SD = 1.9 for SHT and mean = 4.7, SD = 1.7 for SS). However, it was in Biology and Geology contents teaching where the students, regardless of their upper-secondary education path, showed greater self-efficacy (mean = 6.4, SD = 1.8 for SHT and mean = 4.8 SD = 1.6 for SS).

In order to determine whether there were significant differences in terms of the upper-secondary education path, Mann-Whitney *U*-test was applied. These differences were found to be significant in the case of Physics/Chemistry (*p*-value = 0.043) but not for Biology/Geology. Regardless of their education path and gender, prospective teachers felt equally qualified to teach Biology/Geology, which was also the scientific area toward which they felt the most positive emotions. However, significant differences were found for Physics/Chemistry, being determinant for feeling greater self-efficacy in teaching this content if the student had completed an SHT upper-secondary education path.

Objective 3. Multiple Intelligences

After analyzing the students' multiple intelligences, the distribution in **Table 2** was obtained, showing mean, SD, Cronbach's alpha, skewness, kurtosis and the distribution in percentages of the predominant learning styles indicated by the prospective teachers, some of whom claimed to have more than one. The predominant learning style was selected to develop the analyses.

Based on this, it can be said that the bodily-kinæsthetic intelligence was predominant in 23.1% of the sample. On the other hand, visual-spatial intelligence was the least present in the sample in this study (7.5%). All the intelligence profiles were found to be represented. The negative value of the skewness in all intelligences types, except for linguistic, shows that the mode value is displaced to the right respect to the normal distribution, resulting in a dominant left tail. Kurtosis describes if those tails are pronounced, in our case, all values are negative, showing flattened distribution with short tails.

Since in the classification of Multiple Intelligences there is a differentiation between naturalistic intelligence and logical-mathematical intelligence, we wanted to determine whether this differentiation can be justified with our data. Spearman's correlations were used to see if those prospective teachers with

TABLE 2 | Descriptive statistics and distribution of the students' learning styles.

	Scale range	Mean	SD	α	Skewness	Kurtosis	Distribution (%)
Logical-mathematical	1–5	3.342	0.728	0.719	−0.315	−0.320	18.1
Linguistic	1–5	3.337	0.727	0.715	0.020	−0.622	18.1
Naturalistic	1–5	3.210	0.875	0.814	−0.035	−0.471	16.2
Musical	1–5	3.305	0.875	0.818	−0.023	−0.642	17.5
Kinaesthetic	1–5	3.567	0.766	0.602	−0.471	−0.415	23.1
Visual-spatial	1–5	3.164	0.753	0.717	−0.232	−0.543	7.5

TABLE 3 | Spearman's correlation coefficients between positive and negative emotions toward physics and chemistry and the different multiple intelligence profiles.

		Logical-Mathematical	Naturalistic	Kinæsthetic	Visual-Spatial
Positive emotions	Physics and Chemistry	0.439**		0.242*	0.259**
	Biology and Geology	0.220*	0.272***	0.228**	0.212*
Negative emotions	Physics and Chemistry	−0.329***			−0.212*
	Biology and Geology				−0.211*

Sig.< 0.05; ** Sig.< 0.01; * Sig.< 001.*

naturalistic intelligence also had logical-mathematical intelligence. The results (Spearman's rho = 0.083; p-value = 0.321) suggested that there is no such correlation, and that having certain naturalistic aptitudes does not imply also having logical-mathematical intelligence. Feeling positive emotions toward Biology/Geology does not imply feeling them toward Physics/Chemistry as well, and, in the same way, having a predominantly naturalistic intelligence does not correlate with having a logical-mathematical intelligence profile.

We wanted to determine whether students with an SHT upper-secondary education scored higher on logical-mathematical intelligence items than those with an SS upper-secondary education. Mann-Whitney U-test was used. The data obtained showed that these differences were significant. The students originally from SHT upper-secondary education obtained higher scores than those from SS upper-secondary education (p-value < 0.001).

Objective 4. Correlations Between the Three Variables and the Variable Predictors of the Emotional Dimension and Self-Efficacy

With regard to the last of the proposed objectives, we wanted to determine whether the prospective teachers who express positive nor negative emotions toward Physics/Chemistry have a more logical-mathematical or visual-spatial profile. For this, we used Spearman's correlations (**Table 3**).

These results provide new data that has not been studied previously. A significant correlation was obtained between feeling positive emotions toward Physics/Chemistry and having a logical-mathematical or visual-spatial intelligence profile (p-value < 0.001). This correlation of positive emotions toward Physics/Chemistry was non-existent when talking about naturalistic intelligence. It is necessary to specify and distinguish clearly when talking about the positive emotions that these students feel toward science. However, it can be seen that the correlation was significant when referring to positive emotions in Biology/Geology and naturalistic intelligence (p-value < 0.001). No correlations were found for linguistic and musical intelligences. Inverse and significant correlations were obtained between feeling negative emotions toward Physics/Chemistry and having logical-mathematical (p-value < 0.001) and visual-spatial intelligences (p-value < 0.01).

With respect to self-efficacy, we wanted to determine whether the students who felt greater self-efficacy in Physics/Chemistry had a predominant logical-mathematical intelligence. We used Spearman's correlations, with the p-values being listed in **Table 4**.

This study yielded very interesting data about the students' self-efficacy and their different intelligence profiles. There were also correlations between having a high perception of self-efficacy when teaching Physics and Chemistry contents and the logical-mathematical intelligence (p-value < 0.01) and visual-spatial profiles (p-value < 0.05). It could be surprising that the correlation is even stronger between having a high perception of self-efficacy when teaching Biology and Geology contents, having logical-mathematical (p-value < 0.001), and visual-spatial intelligence (p-value < 0.01).

Our results allow us to state that there is a positive and significant correlation between having logical-mathematical intelligence and feeling positive emotions toward the contents of Physics and Chemistry and Biology and Geology. Regardless of the methods used in their classrooms throughout their previous stages of schooling, these students present positive emotions toward sciences. Likewise, there are inverse and significant correlations between having logical-mathematical intelligence and feeling negative emotions toward the contents in Physics and Chemistry. In this study, it can be seen that having a high perception of self-efficacy when teaching Physics and Chemistry and Biology and Geology correlates with logical-mathematical intelligence but not with naturalistic intelligence. Possessing a naturalistic intelligence is not equivalent to possessing a

TABLE 4 | Spearman's correlation coefficients between self-efficacy in different scientific areas and the students' intelligence profiles.

	Logical-mathematical	Linguistic	Naturalistic	Musical	Kinæsthetic	Visual-spatial
Physics and Chemistry	0.247**	0.089	0.112	0.087	0.091	0.207*
Biology and Geology	0.284***	0.074	0.111	0.087	0.104	0.218**

**Sig.< 0.05; ** Sig.< 0.001.*

TABLE 5 | Multiple regression analyses (stepwise method): the predictor variables.

Dependent variable and step	β	p	R^2
Positive emotions toward Physics and Chemistry			0.366
1. Positive emotions toward Biology/Geology	0.364	<0.001	
2. Logical/Mathematical MI	0.239	<0.001	
3. Self-efficacy	0.164	0.024	
Negative emotions toward physics and Chemistry			0.579
1. Negative emotions toward Biology/Geology	0.412	<0.001	
2. Positive emotions toward Biology/Geology	0.651	<0.001	
3. Positive emotions toward Physics/Chemistry	−0.486	<0.001	
4. Gender	0.170	0.004	
5. Self-efficacy	−0.173	0.004	
Positive emotions toward Biology and Geology			0.557
1. Positive emotions toward Physics/Chemistry	0.599	<0.001	
2. Negative emotions toward Physics/Chemistry	0.652	<0.001	
3. Positive emotions toward Biology/Geology	−0.350	<0.001	
4. Self-efficacy	0.137	0.029	
Negative emotions toward Biology and Geology			0.334
1. Negative emotions toward Physics/Chemistry	0.684	<0.001	
2. Positive emotions toward Biology/Geology	−0.557	<0.001	
3. Positive emotions toward Physics/Chemistry	0.428	<0.001	
4. Upper Secondary Education	0.148	0.039	
Self-efficacy for teaching Physics and Chemistry content			0.224
1. Upper Secondary Education	0.344	<0.001	
2. Positive emotions toward Physics/Chemistry	0.250	0.001	
3. Negative emotions toward Biology/Geology	−0.209	0.005	
Self-efficacy for teaching Biology and Geology content			0.266
1. Upper Secondary Education	0.348	<0.001	
2. Positive emotions toward Physics/Chemistry	0.277	<0.001	
3. Negative emotions toward Biology/Geology	−0.212	0.004	

logical-mathematical intelligence–Gardner already intuited this when he differentiated between these two learning styles.

A regression analysis was performed to examine the predictors of the emotional dimension toward sciences of prospective Primary teachers. Percentage of positive emotions toward Physics and Chemistry was the dependent variable, and predictors were gender, self-efficacy, positive emotions toward Biology and Geology, and the multiple intelligences profiles related. Feeling positive emotions toward Physics and Chemistry was significantly predicted by positive emotions toward Biology and Geology (β = 0.364, see **Table 5**), to possessing logical-mathematical intelligence (β = 0.293) and having a high perception of self-efficacy teaching Physics and Chemistry (β = 0.164). This indicates that prospective teachers with high levels of mentioned variables were more likely to present positive emotions toward contents of Physics and Chemistry. The model explained a substantial proportion of variance 33.6% (R^2 = 0.336).

With regard to the negative emotions, percentage of negative emotions toward Physics and Chemistry was the dependent variable, and predictors were gender, self-efficacy, positive and negative emotions toward Biology and Geology, positive emotions toward Physics and Chemistry and the multiple intelligences profiles related. Feeling negative emotions toward Physics and Chemistry was significantly predicted by the negative (β = 0.412) and positive (β = 0.651) emotions that they feel toward Biology and Geology, and the positive emotions that they feel toward Physics and Chemistry (β = −0.486), gender (β = 0.170) and the self-efficacy toward Physics and Chemistry (β = 0.173). This indicates that the emotions, gender and the self-efficacy are predictors of the negative emotions that prospective teachers feel toward Physics and Chemistry content. The model explained a significant proportion of variance 57.9% (R^2 = 0.579).

With respect to the positive emotions toward Biology and Geology, the predictor variables were gender, secondary school track, self-efficacy, positive and negative emotions toward Physics and Chemistry, negative emotions toward Biology and Geology and the multiple intelligences profiles related. The model shows that the positive (β = 0.599) and negative (β = 0.652) emotions toward Physics and Chemistry, negative emotions toward Biology and Geology (β = −0.350) and the perception of self-efficacy (β = 0.137) are predictors of the positive emotions toward Biology and Geology. The model explained the 55.7% of variance (R^2 = 0.557). This indicates that none of multiple intelligences profiles nor gender serve to predict the positive emotions toward Biology and Geology but emotional dimension and self-efficacy.

Concerning negative emotions toward Biology and Geology, the predictor variables were gender, secondary school track, self-efficacy, positive and negative emotions toward Physics and Chemistry positive emotions toward Biology and Geology, and the multiple intelligences profiles related. The model shows that negative (β = 0.684) and positive (β = 0.428) emotions toward Physics and Chemistry, and positive emotions toward Biology and Geology (β = −0.557) and the upper secondary school are predictors of the negative emotions toward Biology and Geology. The model explained the 33.4% of the variance (R^2 = 0.334). This indicates that neither the multiple intelligences profiles, nor gender, nor self-efficacy serve to predict the negative emotions toward Biology and Geology. However, emotions toward sciences and the upper secondary education can predict the negative emotions toward Biology and Geology.

Finally, regarding to perception of the self-efficacy toward Physics and Chemistry and Biology and Geology (both represented at **Table 5**), the predictor variables were gender, secondary school track, positive and negative emotions toward sciences, and multiple intelligences profiles related. Having a high perception of self-efficacy was significantly predicted by the upper secondary education (β = 0.344 for Physics and Chemistry and β = 0.348 for Biology and Geology), the positive emotions toward Physics and Chemistry (β = 0.250/β = 0.277) and the negative emotions toward Biology and Geology (β = −0.209/β = −212). Both models explained a moderate proportion of variance 24.4% (R^2 = 0.244) and 26.6% (R^2 = 0.266) respectively. That means that neither the gender, nor the multiple intelligences profiles can predict the perception of self-efficacy of prospective Primary teachers when they teach sciences. However, both upper secondary education and emotional performance toward sciences can predict the self-efficacy perception of prospective Primary teachers.

DISCUSSION

In this study, authors aimed to describe the emotional dimension of a Spanish prospective teachers' sample toward different sciences fields, intending to establish correlations with their self-efficacy and with their multiple intelligences.

Work by Dweck and colleagues indicates that people's implicit beliefs (particularly about their own emotions) may predispose them toward emotion regulation approaches that have significant consequences for well-being and psychological distress (De Castella et al., 2013). Science educators should provide a cooperative and supportive classroom climate, for those students who remain affected by negative emotions such as anxiety or fear (Britner, 2008). The emotions that prospective teachers experience toward science contents predetermine the emotions that they will transfer to their upcoming students (Borrachero et al., 2013). Emotions greatly influence cognition, motivation, interest, and science learning, so it is necessary for teachers to be aware of the potential of emotions and how they influence the development of the classroom. This would help them to carry out their tasks by applying different methods and making decisions to foster positive emotions during the learning of science (Tomas et al., 2016).

Teacher training process should contemplate the emotional dimension in order to improve the emotions that they feel, providing them with experiences that provoke changes on them turning negative emotions into positives ones. Differences by gender have been explored and our results agree with numerous studies which have found these gender differences toward the sciences in students, differentiating between Physics/Chemistry and Biology/Geology, with women mainly choosing topics related to Biology (Steegh et al., 2019). In other research with prospective teachers, was reported that men tend to express positive emotions more frequently than women (Borrachero et al., 2014). Many studies warn of a significant gender gap in STEM education (Steegh et al., 2019). Primary and early childhood teachers are potentially involved in the development of vocational interests among children, and gender stereotypical beliefs should be also tackled for the purpose of rise in gender equity in education (Makarova et al., 2019). Depending on the upper secondary education path, biology is the favorite science for the prospective teachers to teach, uninfluenced by gender or the upper-secondary education path. In all cases, it generates very few negative emotions, as also has been shown by other studies (Ochoa-De Alda et al., 2019) which note the low intensity of the presence of negative emotions toward Biology.

With regard to prospective teachers' scientific self-efficacy, previous studies have already shown the correlation existing between the emotional component and self-efficacy (van Aalderen-Smeets et al., 2012; Putwain et al., 2013) which also functions as a predictor of academic success in the study of the sciences (Britner, 2008; Oloo et al., 2019), and helps to establish learning strategies (Wu et al., 2019). Possessing a high perception of self-efficacy has a great influence on the emotions that prospective teachers feel when they teach science (Brígido et al., 2012), and is in a modest but significant way also related to the academic success of their pupils (Klassen and Tze, 2014). Depending on gender, our results are in agreement with those obtained in the study by Britner (2008) who reported no significant differences regarding self-efficacy depending on gender in sciences classes. Regarding to the upper secondary education path, our findings are in accordance with the study by Martín-Díaz (2006), which concluded that teachers' original secondary education path influences them decisively when teaching science.

Both educational curricula and IQ tests have traditionally been based on associating intelligence with mathematical or linguistic competencies. Gardner argues, however, that human intelligence cannot be simplified to a single number. The perspective provided by this theory allows each student to be valued individually, making them participants in their teaching-learning process with the use of the contributions of neuroscience (Fischer et al., 2007). Studies carried out with secondary education pupils have shown the potential cognitive and emotional benefits of teaching science through multiple intelligences (Sanchez-Martin et al., 2017). Theoretical and practical implications can be extracted from this section.

Curriculum and academic practice should be reedited and modified in order to adapt teaching including multiple intelligences, what is supported by neuroscience foundations (Shearer, 2018). That could help to improve their self-efficacy, which is extremely related with the emotional dimension and the learning process (Putwain et al., 2013). Eccles and Wigfield (2002) concluded that self-efficacy are the major determinant of goal settings and disposition to effort and persist. Self-efficacy and multiple intelligences correlation has been studied previously and correlation with the academic performance of undergraduate students was shown (Dragoshi and Samuel, 2016). Our results agree with studies of Mahasneh (2013) and Aghajani (2018) who analyzed multiple intelligences of students at higher education and concluded that self-confident and self-efficacy are influenced by the multiple intelligence.

Concerning Multiple intelligences, analysis carried out show the necessity to establish differences between the naturalistic and logical-mathematical intelligence profiles. These results have already been found in the research study of Rosiña et al. (2020) who did not find these correlations in a sample of primary and secondary education pupils. The present data confirm that this lack of correlation is plausible at all educational stages. That research also highlights the importance of knowing the learning styles of the pupils. This is necessary so as to know how to handle emotions. Pupils who had a logical-mathematical intelligence also reported having more positive attitudes and emotions toward scientific subjects.

With the analysis in our sample of intelligence profiles, and taking into account the high representation of the kinæsthetic learning style, it would be interesting to work with pupils of this type. Contents promoting physical and sports activities in the classes should be included, taking advantage also of the relevance that this has on learning and how it promotes neurogenesis (Hillman et al., 2008; Kempermann, 2012) and the improvement of memory (Erickson et al., 2011), in addition to obviously contributing significantly to improve the pupils' health (Hernández et al., 2015).

According to Shearer (2018) the use and application of multiple intelligences' theory in the classroom is supported by neuroscience and it would provokes numerous changes when conducting a class. We think that it is appealing that our sample, as prospective teachers, learn about different learning styles. It would be interesting that in their future work as teachers, they should know what the learning styles of their pupils are, and stimulate meaningful learning by adapting and facilitating the access to information in the most appropriate way according to those profiles. They can not forget that it is necessary to develop all the intelligence profiles in their pupils. Even when a pupil might prefer just one, the teacher must ensure that the pupil manages to improve and enhance skills related to other learning styles (Yaghoob and Hossein, 2016).

CONCLUSION AND FINAL CONSIDERATIONS

In this research, the emotional dimension of a Spanish prospective teachers' sample toward different sciences fields has been described, and correlations between affective dimension with self-efficacy are reported. Relationship between these factors with their multiple intelligences have been also studied applying multiple regression. Next, a summary of the results obtained, according to the objectives initially proposed, is given.

With regard to the first objective, relative to the emotions prospective teachers feel toward science, the results show that Physics and Chemistry constitute an area that arouses more negative than positive emotions, a fact that is not the case for Biology and Geology. Depending on their pre-university education path, the students with a background in science experience more positive emotions toward the contents of Physics and Chemistry. The linear regression analyses showed that possessing logical-mathematical intelligence and having a high perception of self-efficacy are factors that can predict the positive emotions toward Physics and Chemistry. Gender and self-efficacy are variables that can predict the negative emotions toward Physics and Chemistry. Self-efficacy can also predict the positive emotions toward Biology and Geology. Upper secondary education can predict the negative emotions toward Biology and Geology.

With regard to self-efficacy, there are strong correlations between feeling positive emotions and having a greater perception of self-efficacy, and between feeling negative emotions and having a low perception of self-efficacy, and there are no differences depending on gender. Biology and Geology are the science subjects that the prospective teachers prefer to teach. Upper secondary education and the emotions that prospective Primary teachers feel, can predict the perception of self-efficacy of when they teach sciences, this is not the case for the gender, nor the multiple intelligences profiles.

Finally, about the third and fourth objectives, relative to the profiles of multiple intelligences, we find correlations between having a predominantly logical-mathematical style of intelligence and feeling more positive emotions toward Physics and Chemistry. In addition, students who have a greater self-efficacy when teaching science are those who have a logical-mathematical intelligence. The logical-mathematical intelligence profile of prospective teachers may serve as a predictor of the emotions they will feel toward science. From the results obtained in this study, our future line guides will include the use of Project Based Learning as methodology for teaching sciences at the Degree in Primary Education, the PBL design will be based on this preliminary study. Methodological and practical changes will be implemented to improve the prospective teacher self-efficacy and emotional dimension provided during in their training using Gardner's theory.

This study is relevant principally for three reasons. Firstly, the implications that it has for the initial scientific training of prospective teachers are invaluable since the aim is to address the problem of the decrease in scientific attitudes at its root. In the initial training of teachers, this can be approached through the different science subjects in their degree course, and taking advantage of neurodidactics to provide a solution. Secondly, this first study can serve as the basis for interventions with prospective teachers (at cognitive and emotional levels) with the aim of reversing the negative emotions they feel. And thirdly, it constitutes a new contribution to the field of the didactics of experimental sciences, suggesting new lines of research that will promote the growth of this area, our study contributes to improve the quality of science lessons, supporting that teaching and learning process should be oriented not only to enhance cognitive functions but also other skills and potentials.

LIMITATIONS OF THE STUDY

The questionnaire is self-administered, and the veracity of the data depends on the degree of honesty with which each student has answered. For this reason, future research intends to include additional methods to help eliminate this bias. Despite using a validated questionnaire, alpha Cronbach's value for kinæsthetic learning style obtained was quite low. Also, the sample belongs to a single university, and the results cannot be extrapolated other than to what they represent–a sample of prospective teachers from one university in one Spanish region. However, this is an appropriate approach since it is an exploratory study of the sample with whom we intend to continue working, although with the intention to improve the approach in the future.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Since this piece of research involves data collection from individuals, all procedures performed were in accordance with the ethical standards of the 1964 Helsinki Declaration. Informed consent was obtained from all individuals, and the study was validated by the corresponding Ethical Committee (Comisión de Bioética y Bioseguridad, Universidad de Extremadura). All information about the bioethics and ethics in research activity at the University of Extremadura can be retrieved from http://investigalia.unex.es/#!/page36.do?acond12=es&rcond3.att2=197&kcond92.att3=229. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FC-C, JS-M, and IC-C designed the study. All the authors designed the questionnaire, collected the data, and wrote sections detailing the sample of students and data collection. MH-B performed the data analyses and wrote the first draft of the manuscript. FC-C, JS-M, and IC-C reviewed, edited, and supervised the article. All the authors have made a substantial, direct and intellectual contribution to the work, all them have agreed to the published final manuscript.

FUNDING

This work was funded through the Research Project EDU2016-77007-R (AEI/FEDER, EU), and by the Government of Extremadura (Grant GR18004).

ACKNOWLEDGMENTS

MH-B thanks Spain's Ministry of Science, Innovation and Universities for her pre-doctoral grant (BES-2017-081566).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.604791/full#supplementary-material.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
published: 26 March 2021
doi: 10.3389/fpsyg.2021.606153

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Evolution of Prospective Secondary Education Economics Teachers' Personal and Emotional Metaphors

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OPEN ACCESS

Edited by:
David Gonzalez-Gomez, University of Extremadura, Spain

Reviewed by:
Elisabeth Wegner, University of Freiburg, Germany
Maria Grazia Rossi, Universidade NOVA de Lisboa, Portugal

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *14 September 2020*
Accepted: *23 February 2021*
Published: *26 March 2021*

Citation:
Mellado L, Parte L, Sánchez-Herrera S and Bermejo ML (2021) Evolution of Prospective Secondary Education Economics Teachers' Personal and Emotional Metaphors. Front. Psychol. 12:606153. doi: 10.3389/fpsyg.2021.606153

This study examines personal and emotional metaphors of prospective economics teachers about the roles they themselves as teachers and their pupils would play by analysing their drawings and responses to open questions. This is a longitudinal study that analyses the evolution of future instructors using two periods: before and after their teaching practicum. Metaphors are categorised into four classes: behaviourist/transmissive, cognitivist/constructivist, situative/socio-historical, and self-referential. The categories for emotions are primary or social and positive, negative, or neutral. The results show that the highest percentage of metaphors for the teacher's role in both questionnaires were cognitivist/constructivist. Comparison of the findings before and after the teaching practicum revealed no changes in most of the participants' metaphors and associated models. The analysis also reveals that among those who change, the tendency is to evolve towards more pupil-centred metaphors and associated models. The most common pupil metaphors are behaviourist and cognitivist, increasing after the practicum. Finally, most of the emotions expressed are positive and social, also increasing after the practicum.

Keywords: evolution of personal and emotional metaphors, economics, prospective secondary education teacher, beliefs, educational models, emotions

INTRODUCTION

In 1985, the Joint Council on Economic Education, 1985 of the United States expressed its concern for the need to help teachers teach Economics and highlighted teacher training as a key element in this process. Salemi et al. (2001) insist on initial teacher training as being a step prior to implementing methods of teaching Economics that are based on active learning on the part of the pupils. In the interest of improving the training of Economics teachers, Salemi (2003) proposes a training model that offers ideas about the objectives, content, and methods of teaching the subject and emphasizes the contribution of practice teaching for prospective teachers. Since the 1990s, different lines of research have been developed in economics education, one of them being the study of the concepts and practice of Secondary Education Economics teachers (Travé and Pozuelos, 2008). Understanding the factors that favour or hinder the training and professional development of teachers is an essential element in planning and putting into practice training programs that result in improved teaching and learning in class (Estepa and Cuenca, 2007).

For Molina and Travé (2014), the incorporation of the subject of Economics into Compulsory Secondary Education requires configuring a specific Economics Education, within the general area of Social Sciences Education, to base the initial and ongoing training of teachers in this field on it. However, when prospective secondary teachers begin their Master's course, they do so not only with the knowledge they have acquired in their speciality, but also with ideas, attitudes, and feelings about education, which are usually deeply rooted because of the fruit of the many years they themselves had spent at school, either accepting or rejecting the roles that they saw their teachers as having played (Mahlios et al., 2010). For Löfström and Poom-Valickis (2013), prospective teachers' beliefs about the teacher's role are based on their own school experiences as pupils. They do not easily change their beliefs, and even less so their educational practices because overall educational change is a complex process involving numerous obstacles and impedances (Vázquez et al., 2012). Metaphors provide an indirect way to approach teachers' beliefs about teacher's role, which may be implicit or hidden (Löfström and Poom-Valickis, 2013). Metaphor is a powerful cognitive tool in gaining insight into teachers' beliefs (Wan et al., 2011). This reflection about metaphors may help change their teaching roles, usually constructed throughout their schooling. The analyses of the emotions reflected in the metaphors is also a matter of concern. As Day (1999) suggests, change is not just a matter of the head, but also of the heart. It will be difficult to put changes into effect unless they are compensated affectively.

In this article, we present a descriptive study of a sample of prospective Secondary Education Economics teachers, which analysed the evolution of their personal metaphors about themselves as future teachers and about their pupils' role from before their teaching practicum to after it, as well as the emotions associated with those metaphors. This study was a result of a bigger inter-disciplinary research project conducted by an inter-university team, which investigates teachers of different specialties and levels. Although the samples and the methodology are specific for each study, the theoretical framework is common and has already been described in previous works (Mellado et al., 2016, 2018).

Pre-service Teachers and Metaphors

A metaphor is a symbolic way of describing an idea or concept by replacing it with another word or sentence that has a certain objective or subjectivity similarity for the user of the metaphor. Metaphors are an indispensable mechanism of the mind by which people piece together and create new meaning. They help structure a highly relevant dimension of individual's perceptions and conceptual system (Lakoff and Johnson, 1980).

Teachers often use symbolic and metaphoric language when speaking about their professional ideas and practices (Lakoff and Johnson, 1980). Every teacher elaborates a particular body of professional practical thinking as a result of their own individual activity and relations with their community. It is difficult to access this thinking and provide it with sense since educators have certain views about their vocation, which are tough to communicate in an organised manner.

Metaphors articulate teachers' thoughts and create connections between practical knowledge and in-class life narratives (Buaraphan, 2011; Zhao et al., 2011; Hamilton, 2016). They help give an overall organization and articulation to a teacher's conceptions, roles, and practical knowledge and uncover the implicit referents, which sustain that teacher metaphors have a powerful influence on their teaching behaviour in class (Tobin et al., 1994; Boujaoude, 2000).

Numerous studies have used teachers' metaphors as a methodological tool to analyse their beliefs about teaching and learning (Guerrero and Villamil, 2002; Cassel and Vincent, 2011; Szukala, 2011; Duru, 2015; Seung et al., 2015; Kavanoz, 2016). Previous researches with a focus on pre-service secondary teachers of different specialties (Stofflett, 1996; Mellado et al., 2012; Mellado et al., 2016, 2018) show that the metaphors were not associated with specific content, but were an expression of a general vision of teaching and the role of the teacher, formed from the students' own experiences as pupils at school (Briscoe, 1991).

Therefore, metaphors are a significant matter of study in education research and are potent instruments that help inspire pre-service teachers' reflection (Paavola and Hakkarainen, 2005). Furthermore, they make possible a holistic understanding of what happens in the classroom (Buaraphan, 2011), facilitating to promote links with past experiences (Zhao et al., 2011; Hamilton, 2016).

Lakoff and Johnson (1980) noted that metaphors are essential for education because they can model social realities and become a guide for prospect actions that will adjust to those metaphors: '*In this sense metaphors can be self-fulfilling prophecies*' (p. 156). Through a process of critical reflection, teachers are able to build new roles and change their pedagogical conceptions and teaching practices, while embracing new metaphors, which are compatible with those changes and consistent with the educational styles they want to adopt (Sillmam and Dana, 2001; Heston and Veenstra, 2002; Russell and Hrycenko, 2006; Pinnegar et al., 2011; Thomas and Beauchamp, 2011).

While the literature on teachers' metaphors is extensive, there is still room for progress at least because the analysis of teachers' use of personal metaphors is an effective and extraordinary tool to understand educators' thinking and behaviour in class (Shaw et al., 2008). For instance, Mahlios et al. (2010) state that there have been few longitudinal studies on how instructors' metaphors evolve over time.

Saban (2006) reviewed previous literature on teachers' metaphors and suggested that educators might use metaphors to help their students reflect on their beliefs and values about learning and teaching and on how metaphors change during their professional practice. Seung et al. (2015) also call the use of metaphors as an intervention tool. Therefore, the analysis of their own personal metaphors by pre-service teachers before and after their practicums is important because these metaphors may motivate reflection and can help the students comprehend and self-regulate their roles and be conscious of the intricacies involved in changing those images (Leavy et al., 2007; Seung et al., 2011; Tannehill and MacPhail, 2014; Gosselin and Meixner, 2015).

Emotions and Metaphors

There are emotional aspects that are irrational from a cognitive perspective, but which nevertheless impact teachers' decision making, actions, and conceptions (Buaraphan, 2011). Emotions are mostly essential for pre-service teachers (Hargreaves, 2005) since, at the beginning of their professional lives, they are establishing their teaching approaches, class routines, and strategies. This is particularly important given that, as has been observed in other studies (Sillmam and Dana, 2001), their own time as pupils in school has a strong influence on their conceptions and models of teaching. According to Ng et al. (2010), the first teaching experience changes their beliefs to be more focussed on self rather than students, but other emotional beliefs remain (good teachers being kind, caring, understanding, and charismatic, who assist their students to achieve their goals). Brígido et al. (2013) show that the emotions pre-service teachers felt towards teaching certain subjects during the practicum are related to those they felt when they learned those contents in secondary school. Oosterheert and Vermunt (2001) included the regulation of emotions as a functional component of learning to teach. Teacher training is a stage during which these aspects need to be considered so that prospective teachers will be able to control and self-regulate their emotions. Teaching in the practicum is mainly experienced as emotionally positive by the student to be prospective teachers (for example, emotions like interested, enthusiastic, attentive, satisfied, awaked, elated, etc.), although certain negative emotions (for instance, anxiety, nervousness, worry) are also prevalent during the practicum (Hascher and Hagenauer, 2016).

In this article, we based the definition of emotions proposed by Bisquerra (2000, 63):

> Emotions are reactions to the information we receive in our relationships in the environment. The intensity of the reaction depends on subjective assessments that we make of how this information will affect our well-being. These subjective assessments will involve prior knowledge, beliefs, personal objectives, perception of a challenging environment, etc. An emotion depends on what is important to us.

However, emotions are also produced by the recall or evocation of events that occurred in the past (Damasio, 2010) or the anticipation or expectation of possible future situations (Aguado et al., 2011).

Metaphors are a bridge between affect and cognition. Consequently, they help teachers be aware of their feelings. As noted by Zembylas (2004), teachers' metaphors are especially well suited for expressing their emotions. These metaphors have a major affective component since teachers construct them based on their personal experience. For Eren and Tekinarslan (2013), the affective aspects of the prospective teachers' metaphors should be considered during teacher education to understand how they feel about crucial aspects of the teaching and learning-related processes. In addition, Wegner et al. (2020) considers emotions as an important variable related to metaphor about learning.

Objectives

This article analyses the evolution of prospective Secondary Education Economics teachers' personal and emotional metaphors on teaching and learning. Pre and post practicum questionnaires were used to elicit metaphors and drawing metaphors. The specific objectives are as follows:

1. To describe the nature of personal and emotional metaphors used by teachers, divided into four main categories: behaviourist/transmissive, cognitivist/constructivist, situative/socio-historical, and self-referential.
2. To study the evolution of their personal and emotional metaphors about the teacher's and the pupils' roles before and after their practicum.
3. To determine the evolution of their teaching models associated with metaphors.
4. To analyse the emotions reflected in the emotional metaphors.

MATERIALS AND METHODS

Sample

Spanish Secondary Education teachers are required to hold a previous four-year university degree, which is not oriented towards teaching and a Master's degree course in Secondary Teacher Education – a one-year postgraduate course aimed at the educational preparation of the prospective Secondary Economics teacher. In the first semester, this postgraduate Master's degree includes courses on the psychology of learning, pedagogy, and teaching methods specific to the corresponding specialty, as well as a three-month practicum in a secondary school at the end of the first semester.

The study participants were 27 pre-service teachers of a Secondary Education Teaching Master's course who were specializing in Economics. The academic years were the 2012/2013 and 2013/2014 with samples of 14 (from E1 to E14) and 13 (from E15 to E27) students, respectively. In previous works (Mellado et al., 2017a), we have analysed different aspects of the 2012/2013 course sample (from E1 to E14). In this work, we extend the sample to two academic years.

Table 1 shows the characteristic of the sample participants. The number of participants is 27 (N = 27). By gender, there were 9 men (33.3%) and 18 women (66.6%), and by age, 51.9% were aged between 21 and 25 years, 29.6% were 26 to 30 years, and 18.5% were 31 years or older. By type of degree with which the participants entered the Master's course, most had a (Bachelor's) Degree in Business Administration (DBA) (51.9%), followed by Economics (25.9%), Tourism (18.5%), and Law (7.4%). Finally, 4 participants (14.8%) had teaching experience and 23 (81.2%) did not.

During the courses, participants were informed about the study's objectives and participation was voluntary. To monitor their progress, a questionnaire was conducted before and after the accomplishment of their practicums in secondary schools. In our study, we complied with the ethical procedures for research with human participants. All study subjects were guaranteed confidentiality and anonymity.

Data Collection and Qualitative Analysis

In the methodology, we followed Low's (2015) approach that considers seven steps for a methodological validation: (1) preparing participants, (2) to elicit metaphors, (3) to classify

TABLE 1 | Characteristics of the sample participants.

	Gender	Age	Teaching		Gender	Age	Teaching
E1	M	21–25	No	E15	M	21–25	No
E2	W	21–25	No	E16	M	26–30	No
E3	W	26–30	No	E17	M	21–25	No
E4	W	26–30	No	E18	M	21–25	No
E5	W	>35	Yes	E19	M	21–25	No
E6	W	21–25	No	E20	M	>35	No
E7	W	21–25	No	E21	W	31–35	Yes
E8	W	21–25	No	E22	M	21–25	No
E9	W	21–25	No	E23	W	26–30	No
E10	W	21–25	No	E24	W	>35	No
E11	W	21–25	No	E25	W	26–30	No
E12	W	21–25	No	E26	W	26–30	No
E13	W	31–35	Yes	E27	W	26–30	Yes
E14	M	26–30	No				

metaphors into educational categories, (4) to connect with educational theories or orientation, (5) to establish behaviour stemming from educational orientation, (6) to define a plan for future action, and (7) to evaluate the change in metaphors.

The research team had previous experience through prior work on the metaphors of secondary school teachers of different specialties (Mellado et al., 2012). The data were collected using an anonymous questionnaire. Participants were asked some questions about personal information (gender, age, and previous undergraduate degree) and open questions about their own personal metaphors as teachers and about the metaphors that they identified with pupils' learning and the reasons which led them to choose these metaphors. The use of written prompts or metaphor statements is an efficient way to analyse teacher conceptions about teaching and learning; however, these methods have been criticized for their heavy reliance on the statements to explain the implicit teacher conceptions (Seung et al., 2015). The questionnaire was based on Leavy et al. (2007) and Martínez et al. (2001) as well as our previous studies (Mellado et al., 2016, 2017b). The items about metaphors in the questionnaire are as follows:

1. When you teach in a secondary school classroom, what metaphors would you identify yourself with?
2. Explain the reasons that led you to identify yourself with those metaphors.
3. With what metaphors do you identify pupils in relation to learning?
4. Explain the reasons why you identify pupil learning with these metaphors.
5. Try to make a drawing to better symbolise your metaphors as a teacher and your pupils' relationship with the learning process.

We included metaphors' drawings in the data collection procedures, an instrument validated by prior literature with prospective teachers (McGrath, 2006; Buaraphan, 2011; Löfström et al., 2015). Markic and Eilks (2015) point out that pictures made by educators are like mirrors of their professional identity and may help identify whether a class is teacher-and-content centred or pupils-and-learning centred. Weber and Mitchell (1996) consider that an image has a great potential to express metaphors. Sumsion (2002) used teachers' own drawing to analyse the changes in the professional identity in a beginning teacher. Before giving the participants the survey, we informed them about the significance of metaphors in the educational context. Nevertheless, we did not present any examples of personal metaphors so as not to condition their answers.

To categorise the personal metaphors of the prospective teachers, we leaned on Leavy et al.'s (2007) four classes of metaphors: behaviourist/transmissive – with a passive pupil whose motivation is extrinsic, the instructor as a source of content, and with the distinctive of the classes being centred on the instructor and information; cognitivist/constructivist – with active learners that build their knowledge, an individual process in which the stimulus does not depend on external reinforcement, and with the educator as a helper; situative/socio-historical – where the focus is on the social context in which learning is constructed and learners' motivation arises from the participation in the activities with the educational community; and self-referential – comprising particular metaphors centred on what teaching means for the individuals, with no allusion to components of the exercise of teaching. The meaning that participants gave to the metaphors determined their categorization (Roth, 1993). As Wan and Low (2015) point out, our approach to analyse the elicited metaphors by grouping them into categories has limitations, since the assignment of categories can vary markedly among researchers. In the descriptive analysis, we show the frequencies in each category. To assign a metaphor to one of the categories, the drawings and the reasons given by the participants were examined and discussed among the researchers, contrasting the results with previous studies. Seung et al. (2011) also used comparative methods to analyse teachers' metaphors.

Our analysis of the metaphors' evolution and the changes of the students' didactic models is based on Vázquez et al.'s (2012) progression hypothesis. The evolution from behaviourist/transmissive to constructivist/cognitive and from there to situative/socio-historical was a progression, and the contrary a regression since pupil-centred orientations are an indicator of the implementation of inquiry-based innovative teaching strategies in class, as the National Research Council (1996) advocates. Buchanan (2015) also takes teacher-centred or pupil-centred models as referents for categorization. We take any progression as important in which the prospective teacher changes from behaviourist/transmissive models to cognitive/constructivist or situative/socio-historical ones (both of which express pupil-centred classes). Furthermore, we consider progression to be small when it changes from the cognitive/constructivist category to the situative/socio-historical one. Self-referential metaphors have a very particular meaning that need to be considered specifically in each case. To elaborate **Table 2** on the evolution of the models, we analysed all the metaphors expressed by each participant, following the above criterion of progression/regression/no change. When a participant expressed metaphors of different categories, the category of the dominant metaphors was considered, for which the coherence between the text and the drawings is considered.

TABLE 2 | Evolutions in the teachers' models before and after the teaching practices (*T*, behaviourist/transmissive; C, cognitivist/constructivist; S, situative/socio-historical; R, self-referential).

Participants	Pre-test to post-test evolution of the teacher metaphors	Changes in the teacher metaphors	Pre-test to post-test evolution of the pupil metaphors	Changes in the pupil metaphors
E1	T – T	No change	T – T	No change
E2	T – T	No change	T – T	No change
E3	T – T	No change	T – T	No change
E4	T – T	No change	R – R	No change
E5	C – C	No change	C – C	No change
E6	C – C	No change	C – C	No change
E7	S – S	No change	R – R	No change
E8	S – S	No change	C – C	No change
E9	S – S	No change	C T – T	Regression
E10	T – S	Progression	R – R	No change
E11	T – CS	Progression	R – R	No change
E12	T – S	Progression	C – C	No change
E13	TC – C	Progression	T – C	Progression
E14	C – S	Progression	C – S	Progression
E15	C – C	No change	T – T	No change
E16	C – S	Progression	C – S	Progression
E17	T – T	No change	T – T	No change
E18	S – C	Regression	T – T	No change
E19	CS – C	No change	R – R	No change
E20	T – T	No change	T – T	No change
E21	SC – SC	No change	SC – C	No change
E22	C – S	Progression	CT – S	Progression
E23	S – C	Regression	ST – CT	No change
E24	R – R	No change	C – C	No change
E25	R – C	Progression	C – C	No change
E26	SC – C	No change	SC – C	No change
E27	SC – S	No change	C – C	No change

After examining the pre-test, and before the practicum, we had a group session with the participants in which, using Power Point, we showed them the metaphors and the drawings that had been made to represent them and discussed their meanings. For Tobin and Fraser (1989), the introduction of a variety of metaphors during initial teacher training allows the prospective teachers to gain a view of the potential of metaphors as a tool, to reflect on their own metaphors, and to develop new metaphors consistent with the teaching models they want to implement (Pinnegar et al., 2011). The post-test was conducted after the teaching practicum. Since there were no longer any regular class sessions in any of the Master's course subjects, we collected these in one of the tutoring sessions about those practicums.

As Sutton and Wheatly (2003) point out, teachers' emotions can be analysed through the metaphors they use. In addition, Chen (2003) incorporates emotional metaphors, as teachers describe teaching as feelings, passion, imagination, interest, and creativity.

With respect to discriminating between different types of emotions, there is a lack of consensus among authors. Therefore, we classified the emotions into positive, negative, or neutral and primary or social (Damasio, 2010; Brígido et al., 2013; Hascher and Hagenauer, 2016). Fernández-Abascal et al. (2001) point out that positive emotions involve pleasant feelings, of short duration, and require the mobilization of few resources; negative emotions involve unpleasant feelings, and coping with them requires the mobilization of many resources. Primary emotions are innate and universal (fear, anger, sadness, disgust, and happiness), while secondary ones need a social context, since they are acquired in interaction with others (shame, guilt, pride, enthusiasm, satisfaction, trust, contempt, etc.).

In previous studies (Brígido et al., 2013; Mellado et al., 2016, 2018), we analysed the teacher's emotions, grouped in primary/social and positive/negative. To assign an emotion to one of the categories, the metaphors' drawings and the reasons given by the participants were examined and discussed among the researchers.

RESULTS

Metaphors' Evolution and Associated Teaching-Learning Models

The results are not intended to be generalizable because this was not a statistically representative sample. They need to be seen from an interpretative perspective, seeking the meanings of the participants' individual metaphors.

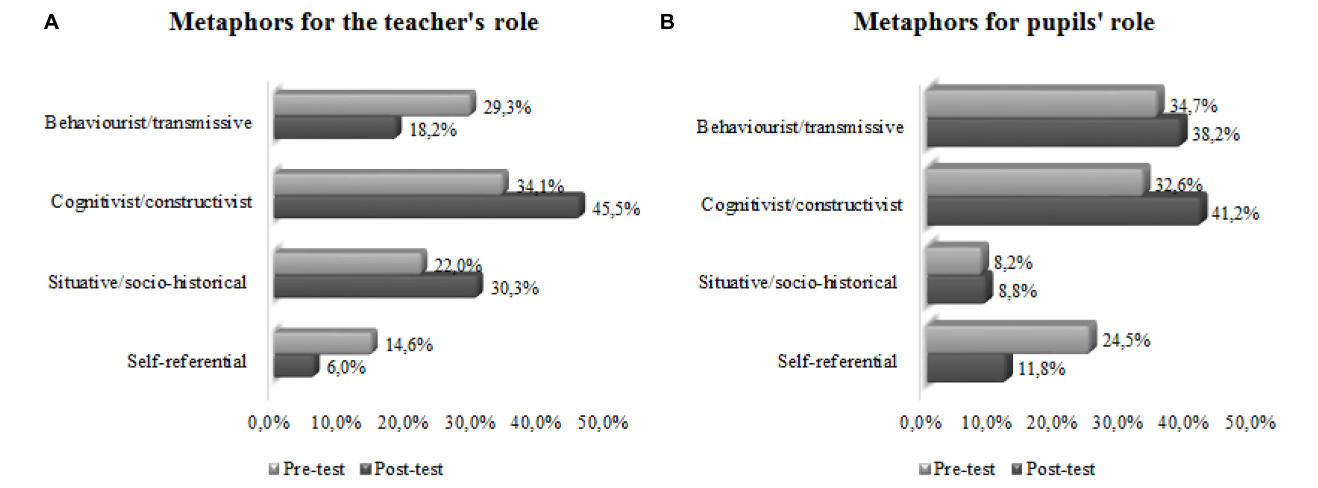

CHART 1 | (A,B) Comparison of the percentages of metaphors for the teacher's and pupil's roles, before and after the practicum.

The 27 participants used 41 metaphors for the teacher's role in the pre-test and 31 in the post-test. **Chart 1A** shows the comparison of the percentages of metaphors in the four categories of study, before (pre-test) and after (post-test) the practicum. In both questionnaires, the highest percentage of teacher metaphors were cognitivist/constructivist. Comparison of the results before and after the practicum showed that the teacher metaphors changed from teacher-centred models (the behaviourist/transmissive category) to others more pupil-centred (cognitivist/constructivist and situative/socio-historical categories).

The participants used 49 metaphors for the pupils' role in the pre-test and 34 in the post-test. **Chart 1B** presents the comparison of the percentages of metaphors in the four categories of study before and after the teaching practices. Before, the greatest percentage corresponded to behaviourist/transmissive pupil metaphors. However, after the practicum, the greatest percentage corresponded to cognitivist/constructivist metaphors, with both these and the behaviourist/transmissive increasing and the self-referential decreasing. This last finding may reflect a relative lack of definition of the models associated with pupil metaphors, models which begin to be more clearly defined after the practicum. In both questionnaires, the students expressed very few situative/socio-historical pupil metaphors.

By individualizing the models associated with each participant's teacher and pupil metaphors, we were able to monitor their progress. **Table 2** lists the changes observed from pre- to post-practicum for each of the 27 participants. Regarding the teacher's role, 17 (63.0%) participants showed no change in their metaphors, 8 (29.6%) a progressive change, and 2 (7.4%) a regressive change. Regarding the pupils' role, 22 (81.5%) of the participants showed no change in their metaphors, 4 (14.8%) a progressive change, and 1 (3.7%) a regressive change. It was notable that 16 participants (59.2%) changed neither their teacher models nor their pupil models.

FIGURE 1 | Drawings of E1 for the metaphor of the teacher as machine (pre-and post-test).

Next, we shall highlight some examples. Participant E1 maintained his behaviourist/transmissive metaphors, the teacher as a machine (Alarcón et al., 2014), before and after the teaching practicum (**Figure 1**). This metaphor is common in studies of business organizations (Morgan, 1980), representing a traditionalist vision of the firm working as a set of machines in a routine, efficient, precise, and predictable way. For the pupils, he maintains a behaviourist/transmissive metaphor of a sponge (Saban, 2010) representing the pupils as absorbing what the teacher gives them.

While Participant E20 changed his metaphors from before to after the practicum, they remained within the behaviourist/transmissive category. Before, the teacher is seen as an atlas or an encyclopaedia (Thomas and Beauchamp, 2011), and after as a water tank that feeds water to the pupils (**Figure 2**). In both cases the teacher is the transmitter of content and the pupils are passive recipients.

Participant E26 conserved her metaphors within the cognitive/constructivist category. In both surveys, she identified the teacher with the gardener and the pupils with the seeds that germinate and grow (**Figure 3**). The gardener must water and care for all the plants according to their needs (Buaraphan, 2011; Kim and Danforth, 2012; Hamilton, 2016),

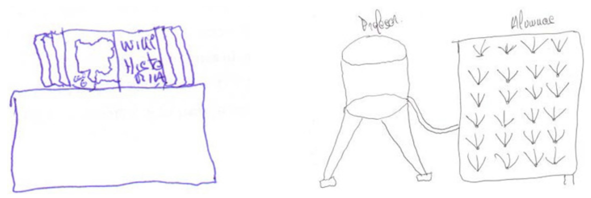

FIGURE 2 | E20's teacher metaphor drawings as encyclopaedia (in the pre-test) and water tank (post-test).

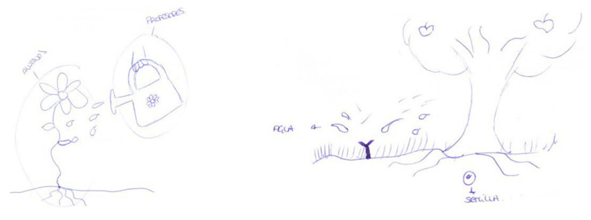

FIGURE 3 | E26's drawings for the metaphor of the gardener for the teacher and the seed for the pupils (pre-test and post-test).

FIGURE 4 | E27's drawings of a class as rowing crew in the pre-test and in the post-test.

a complement to the metaphor of the pupil as a seed (Gurney, 1995; Saban, 2010).

Participant E27 maintained a situative/socio-historical metaphor of a rowing crew both before and after her practicum (**Figure 4**): 'all in the same boat rowing in the same direction'. This is a metaphor identified by Buaraphan (2011) in which cooperation is necessary since if there is no cox, then the boat will go off-course; however, if the oarsmen stops rowing, then the boat will stop.

Participant E23 expressed a small regression while remaining within the pupil-centred models. In the pre-test, she gave the situative/socio-historical teacher metaphor of a lighthouse (McGrath, 2006), and in the post-test, the cognitive/constructivist metaphor of the teacher watering flowers (**Figure 5**).

An example of an important progression in the teacher metaphor is that of E11. In the pre- test, she identifies the teacher with the metaphor of an ant (Saban, 2010), because of its hard-working nature. We classify this as behaviourist/transmissive since the drawing (**Figure 6**) shows the ant writing on the blackboard with its back to the pupils and without their participation. However, in the post- test her teacher metaphors are those of a sower of seeds (of cognitive/constructivist characteristics) and of a guide dog (which we classified as between situative/socio-historical for being a guide (Huang, 2017) and cognitive/constructivist for representing an aid to the blind pupil who she sees as being someone who makes their own decisions).

Evolution of the Emotional Metaphors

Regarding the teacher's role, the participants used 34 emotional metaphors in the pre-test and 31 in the post-test. **Chart 2A** shows the comparison of the percentages of emotional metaphors in the four categories of study before and after the practicum. In the pre-test, the greatest percentage of teacher emotional metaphors were cognitivist/constructivist, followed by situative/socio-historical, behaviourist/transmissive, and self-referential. In the post-test, there was a large increase in the percentage of situative/socio-historical and a small increase in that of cognitivist/constructivist, and decrease in the behaviourist/transmissive and self-referential.

Regarding the pupils' role, the participants used 33 emotional metaphors in the pre-test and 29 in the post-test. **Chart 2B** presents the comparison of the percentages of emotional metaphors in the four categories of study before and after the practicum. In the pre-test, the greatest percentages of pupil emotional metaphors were behaviourist/transmissive and cognitivist/constructivist, followed by self-referential, and situative/socio-historical. In the post-test, there was an increase in the cognitivist/constructivist and situative/socio-historical percentages, and decrease in the behaviourist/transmissive and self-referential metaphors.

We would emphasize that, for both the teacher and the pupil metaphors, the greatest number of emotions were the positive social ones, which increased after the practicum (**Charts 3A,B**). No neutral emotions were identified. We also

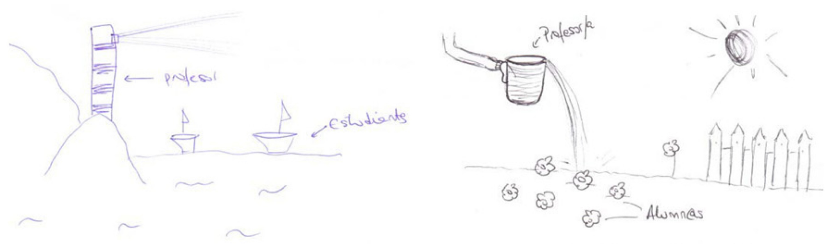

FIGURE 5 | E23's drawings for the metaphors of a lighthouse that guides boats (pre-test) and watering the flowers (post-test).

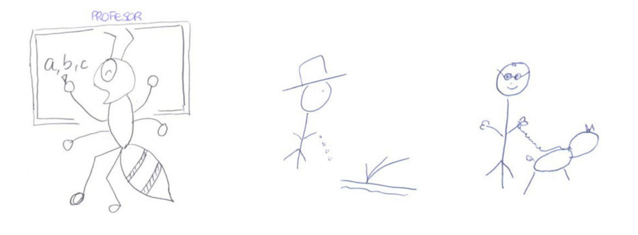

FIGURE 6 | E11's drawings for the metaphor of the teacher as an ant explaining on the board (pre-test) and as a sower of seeds and a guide dog (post-test).

identified metaphors reflecting primary emotions: positive like happiness (the sun that gives light and heat for the teacher and the flowers in a garden for the pupils) and negative like fear (lamb among wolves for the teacher).

In the following paragraphs, we present some of the participants' emotional metaphors.

Metaphors reflecting positive primary emotions: happiness. Among the teacher, examples are butterfly fluttering among the flowers, a self-referential metaphor drawn by student E24 and the Sun that gives light and heat drawn by student E6 (**Figure 7**).

Metaphors reflecting negative primary emotions: Fear. For the teacher's role, we identified the emotion of fear in the metaphor of a lamb among wolves (E3). No negative primary emotions were identified for the pupils' role.

Metaphors reflecting positive social emotions: Enthusiasm, confidence, protection, etc.

Enthusiasm, emotion collected by Eren and Tekinarslan (2013). An example is that drawn by student E14 (**Figure 8**) of the teacher and pupils as mountain climbers who can overcome difficulties and reach the summit. It has a situative/socio-historical meaning, representing teamwork and the teacher as a guide (Cassel and Vincent, 2011; Patchen and Crawford, 2011).

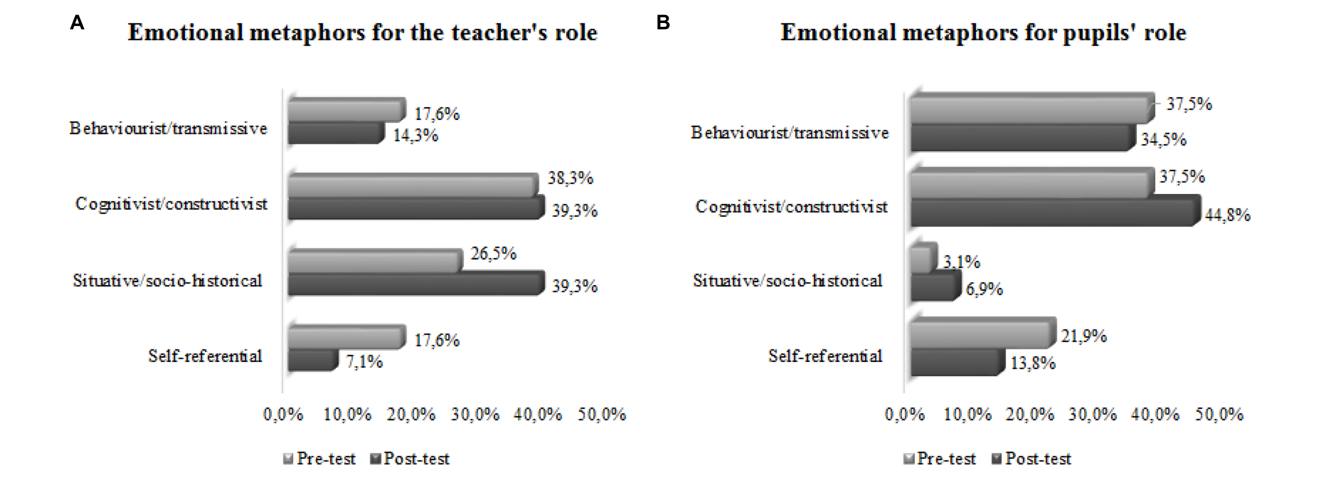

CHART 2 | (A,B) Comparison of the percentages of emotional metaphors for the teacher's and pupil's roles, before and after the practicum.

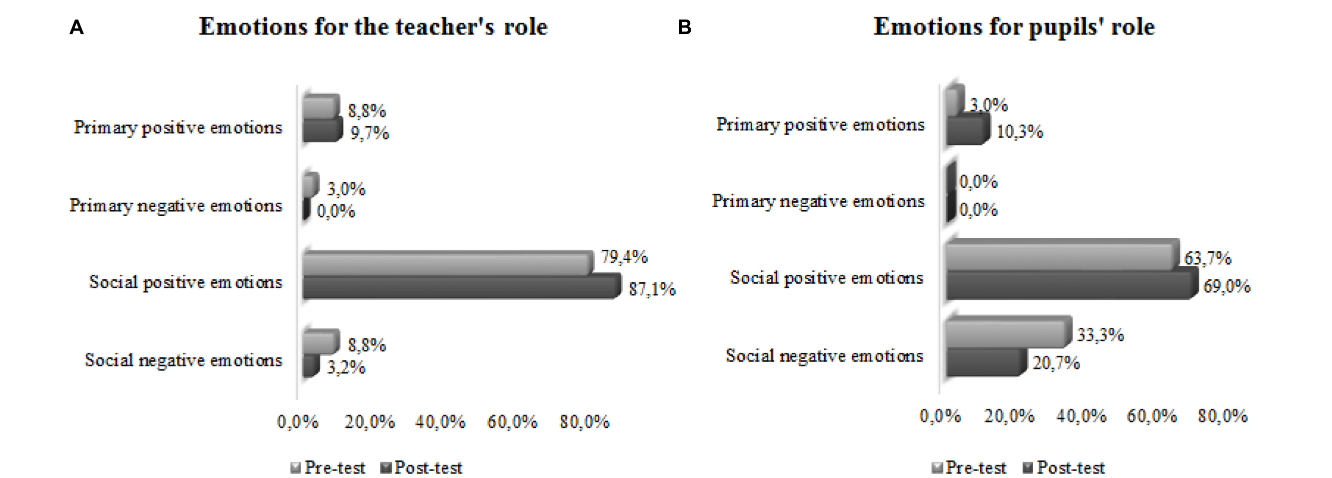

CHART 3 | (A,B) Comparison of the percentages of emotions for the teacher's and the pupils' roles, before and after the practicum.

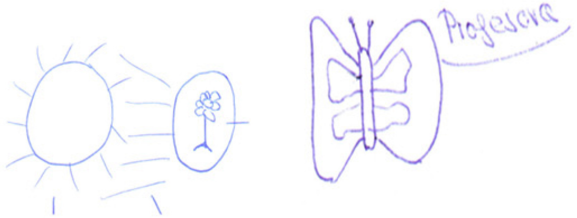

FIGURE 7 | Drawings of the teacher as Sun and butterfly.

FIGURE 10 | Drawing of the teacher as a guide dog and guiding and protecting fledgling birds.

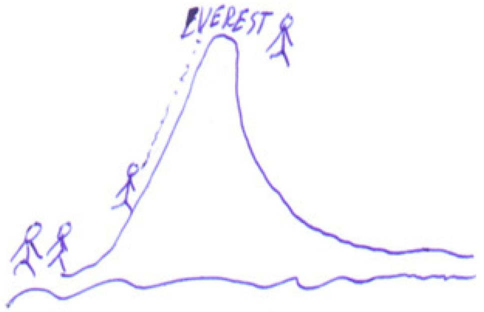

FIGURE 8 | Drawing of the teacher and pupils as mountain climbers.

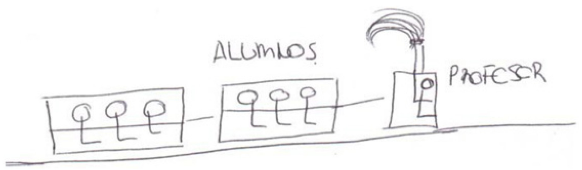

FIGURE 9 | Drawing of the teacher as an engine driver.

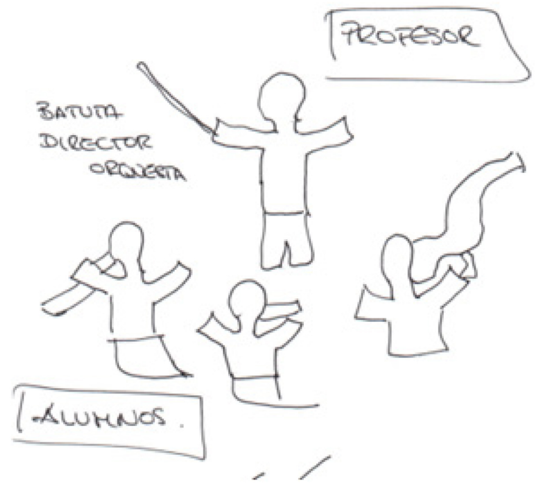

FIGURE 11 | Drawings of the teacher as an orchestra conductor and the pupils as musicians.

FIGURE 12 | Drawings of the teacher's killer look.

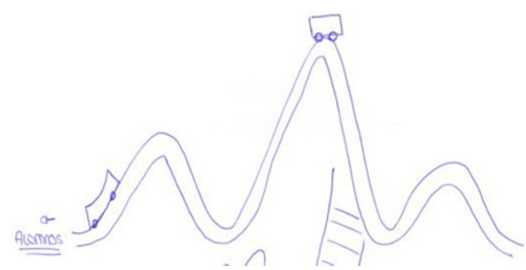

FIGURE 13 | Drawings of the roller coaster as metaphor for the pupils.

Confidence, emotion collected by Plutchik (2001). The drawing of E21 (**Figure 9**) represents the teacher as an engine driver, who gives the pupils safety and trust.

Protection, emotion related to affection, empathy, etc., emotions collected by Bisquerra (2019). The teacher metaphor of a guide dog can be classified as somewhere between situative/socio-historical (for being a guide) and cognitive/constructivist (for being an aid to the blind person, i.e., the pupil, who nevertheless makes their own decision). The case is similar to the teacher metaphor of someone who takes care of and guides fledgling birds (**Figure 10**) when they leave (E15) or return (E19) to the nest.

Stimulus, motivation. Several participants identified the teacher with being some sort of a guide to motivate their pupils (Thomas and Beauchamp, 2011). Student E8, for instance, sees the teacher as an orchestra conductor (Ben-Peretz et al., 2003; Leavy et al., 2007; Seferoglu et al., 2009); thus, reflecting these stimulus and motivation emotions (**Figure 11**), with the conductor directing a group of musicians but each pupil playing a different instrument. '*The orchestra conductor is the leader who is aware of individual differences and needs, and through successful collaborative work both parties enhance a mutual goal*' (Akar and Yildirim, 2009, p. 406).

Metaphors reflecting negative social emotions: Intimidation, insecurity, control, etc.

Intimidation, hostility, emotions collected by Bisquerra (2019). The teacher metaphors expressed by E2 of a killer look (pre-test, **Figure 12**) and a wolf's stare (post-test) have a high degree of aggressiveness and are coherent with the pupil metaphor expressed by this participant – as bugs that never stop moving about.

Insecurity, emotion collected by Bisquerra (2019). This emotion is associated with E7's pupil metaphor of the roller coaster (**Figure 13**) as reflecting the changes in character that adolescents undergo in their everyday lives.

DISCUSSION AND CONCLUSION

The study shows that all the participants were able to conceptualize both the pupils' role and their own role as future teachers in the form of metaphors. Their written texts and their pictures were both found to be extraordinary tools to help make the metaphors' meanings concrete. In their explanations of the reasons for identifying with their personal metaphors, the senses of the writing and the drawing most often matched; however, in those cases in which there were differences, we consider that the drawing better represented the metaphors' meaning (Weber and Mitchell, 1996; Markic and Eilks, 2015).

In both questionnaires, before and after the practicum, the greatest percentage of teacher role metaphors corresponded to the cognitivist/constructivist category, followed by behaviourist/transmissive in the pre-test and situative/socio-historical in the post-test. In the post-test, we observed increased percentages of cognitivist/constructivist and situative/socio-historical metaphors and a decrease in the behaviourist/transmissive. After a training program, Leavy et al. (2007) indicate an increase in cognitivist/constructivist metaphors and a decrease in behaviourist/transmissive. In addition, Alger (2009), finds that older teachers start teaching with teacher-centred metaphors, and during their careers, some switch to student-centred metaphors. The greatest number of teacher metaphors that belonged to the cognitivist/constructivist category is coherent with the results of another study with prospective secondary school educational guidance teachers (Mellado et al., 2016), but not with the findings of a study of prospective secondary school science teacher (Mellado et al., 2017b) that express a greater number of behaviourist/transmissive metaphors. Among the metaphors most indicated for the teacher role are that of the open book (behaviourist/transmissive), the farmer-sower (cognitivist/constructivist), and the guiding light (situative/socio-historical).

The greatest percentage of pupil role metaphors pre-test corresponded to the behaviourist/transmissive category, followed by cognitivist/constructivist; however, in the post-test, the greatest percentage of pupil metaphors corresponded to cognitivist/constructivist, followed by behaviourist/transmissive and self-referential. In both questionnaires, the lowest percentage of pupil role metaphors corresponded to the situative/socio-historical category, a result that coincides with samples of other specialities (Mellado, 2017). For the pupil metaphors in the post-test, there was an increase in the percentage of cognitivist/constructivist and behaviourist/transmissive and a decrease in the self-referential, with the situative/socio-historical metaphors showing just a slight increase. For the role of the pupils, the metaphor of a sponge (Saban, 2010) was the most common. Animal metaphors were also common for pupils, many of them classified as self-referential: ant, cicada, fly, cow, pig, sheep, snail, turtle, lynx, fox, owl, etc.

There are differences between the metaphors of the role of the teacher and those of the student body, with the teacher generally representing more student-centred models. In some cases, there is coherence between the metaphors of the teacher and those of the student: for example, the guiding lighthouse corresponds to the ships guided by the lighthouse, the gardener corresponds to the seed that germinates and grows, and the water tank corresponds to the garden that receives the water. However, in other cases, there is a lack of coherence, as Strugielska (2008) has already observed: the conductor does not correspond to the hair that grows or the light that illuminates does not correspond to puppets.

A result that coincides with previous studies (Mellado et al., 2012, 2016, 2018) is that the metaphors were not associated with specific content, but were an expression of a general vision of teaching and the role of the teacher, formed from the students' own experiences as pupils at school (Briscoe, 1991). This is coherent with the finding of Stofflett (1996) that teachers develop metaphors grounded in their personal histories as learners and educators, and that their metaphors are not associated with subject matter.

Comparison of the two sets of results showed that 63.0% of participants for the teacher's role and 81.5% for the pupils' role did not change their metaphors and associated models. This result is consistent with the results of previous empirical studies that analyse similar samples of secondary school teachers in training in other specialties, such as science or educational guidance, in which 76.7 and 66.6% did not change the metaphors for the teacher's role, respectively (Mellado et al., 2016, 2018). These findings are indicative of the difficulty the prospective teachers have in changing their metaphors and associated teaching models because these are already firmly settled when they begin their Teacher Education Master's course and remained uninfluenced by either the course or the practice teaching. Shaw and Mahlios (2011) reported that most of the subjects in their studies maintained their metaphors unchanged over the years of their teacher education.

However, with respect to those who did change, 29.6% participants showed a progressive change for the teacher's role and only 7.4% a regressive change. Tannehill and MacPhail (2014) noted that several pre-service teachers, as a result of experience, coursework, and peer discussion, moved from initially viewed themselves as transmitters of knowledge towards a more constructivist notion of teaching and learning. Furthermore, Akar and Yildirim (2009), Löfström and Poom-Valickis (2013), Kavanoz (2016), and Seung et al. (2011) found that when changes occur the metaphors tended to express more pupil-centred educational models. For the pupils' role, 14.8% participants showed a progressive change and 3.7% a regressive change.

These findings show that, although most of the participants did not change their metaphors and associated models, there was still a relevant fraction of them who underwent a progressive evolution towards more pupil-centred educational models. During the Master's degree, it is the first time that these pre-service teachers have had contact with education or psychology subjects and they have been in teaching practices, but in this research, we do not have data to determine the specific causes that have stimulated or hindered the changes in the metaphors and associated educational models.

In the pre-test, the greatest percentage of teacher emotional metaphors corresponded to the cognitivist/constructivist, followed by situative/socio-historical, and behaviourist/transmissive. The emotional metaphors corresponded to the cognitivist/constructivist, and they are also the majority in secondary pre-service teachers of other specialties (Mellado et al., 2017b). In the post-test, there was a major increase in the percentage of situative/socio-historical metaphors, a small increase in the cognitivist/constructivist, and a decrease in the behaviourist/transmissive. In the pre-test, the greatest percentage of pupil emotional metaphors corresponded to the behaviourist/transmissive and cognitivist/constructivist, followed by self-referential and situative/socio-historical. In the post-test, there was an increase in the percentages of cognitivist/constructivist and situative/socio-historical and a decrease in the percentage of behaviourist/transmissive metaphors.

For both the teacher and the pupil metaphors, the positive social emotions were the most frequent and they increased after the practicum, coincident results for pre-service secondary teachers of other specialties, such as science, technology, and Educational Guidance (Mellado, 2017). The positive primary emotions also increased after the practicum. For the teacher metaphors, only the negative primary emotion of fear was expressed, and this was in the pre-test, which disappeared after the practicum. For the pupil metaphors, there were no negative primary emotions, but more negative social emotions were expressed than for the teacher, although in both cases, these declined after the practicum.

With respect to the study's implications, it would have been interesting to contrast our interpretation of the metaphors with those of the teachers themselves. It will also have to analyse not only what teachers say but also what they do in their classes to contrast their declared metaphors and models with those that can be observed in their classroom practice. It would also be necessary to analyse the causes of changes or permanence of the metaphors, as well as the cognitive and emotional factors that stimulate or hinder the changes in metaphors. In our study we do not have data on whether the changes in the associated metaphors or models were due to the information and reflection about metaphors made in class with groups of the sample or whether they were due to other factors, such as the theoretical subjects of the Master's degree, or the practicum.

Future research will have to look more deeply into the possibilities of intervention. As Briscoe (1991) asserted, pre-service science teachers' reflection on their own metaphors during practices by contrasting them with those of expert tutors, who have innovative models focused on student learning, facilitate prospective teachers to develop their own didactic knowledge of the content. However, there should be more connection and coherence between theory and practice in the Master's Degree (Allen and Wright, 2014). The practicum may be a great source of professional knowledge, which should stimulate and provide feedback to the metacognitive reflection of the entire Master. However, the finalist teaching practices programmed in the Master of our sample do not meet this objective because they seem to be conceived as a mere application of previous theoretical modules. At the secondary education level, the academist models of teacher education, which are centred on the knowledge of the material to be taught with only a bit of pedagogical knowledge and some teaching practice tacked on at the end are not the most appropriate.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Commission of Bioethics and Biosecurity of the University of Extremadura (Approval No. 158/2020). Written informed consent from the patients/participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

LM conceived and designed the article, collected the data, analyzed and interpreted the data, and wrote the manuscript. LP conceived and designed the article, analyzed and interpreted the data, and wrote the manuscript. SS-H collected the data and analyzed and interpreted the data, and wrote the manuscript. MB collected the data, analyzed and interpreted the data, and wrote the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by the Research Projects EDU2016-77007-R of the Ministry of Science, Innovation and Universities of Spain, GR18132 of the Junta de Extremadura (Spain) and the European Regional Development Fund (ERDF).

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 14 May 2021
doi: 10.3389/fpsyg.2021.658027

When to Scaffold Motivational Self-Regulation Strategies for High School Students' Science Text Comprehension

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OPEN ACCESS

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: 24 January 2021
Accepted: 23 March 2021
Published: 14 May 2021

Citation:
Michalsky T (2021) When to Scaffold Motivational Self-Regulation Strategies for High School Students' Science Text Comprehension. Front. Psychol. 12:658027. doi: 10.3389/fpsyg.2021.658027

Noting the important role of motivation in science students' reading comprehension, this 14-weeks quasi-experiment investigated the optimal timing for implementation of metamotivational scaffolding for self-regulation of scientific text comprehension. The "IMPROVE" metamotivational self-regulatory model (Introducing new concepts, Metamotivation questioning, Practicing, Reviewing and reducing difficulties, Obtaining mastery, Verification, and Enrichment) was embedded at three different phases of secondary students' engagement with scientific texts and exercises (before, during, or after) to examine effects of timing on groups' science literacy and motivational regulation. Israeli 10th graders ($N = 202$) in eight science classrooms received the same scientific texts and reading comprehension exercises in four groups. Three treatment groups received metamotivational scaffolding before ($n = 52$), during ($n = 50$), or after text engagement ($n = 54$). The control group ($n = 46$) received standard instructional methods with no metamotivational scaffolding. Pretests and posttests assessed science literacy, domain-specific microbiology knowledge, and metamotivation regulation. Intergroup differences were non-significant at pretest but significant at posttest. The "before" group significantly outperformed all other groups. The "after" group significantly outperformed the "during" group, and the control group scored lowest. Outcomes suggested delivery of metamotivational scaffolding as a potentially important means for promoting students' science literacy and effortful perseverance with challenging science tasks, especially at the reflection-before-action stage for looking ahead and also at the reflection-on-action stage for looking back. More theoretical and practical implications of this preliminary study were discussed to meet the growing challenges in science teaching schoolwork.

Keywords: metamotivation scaffolding, motivational regulation strategies, science literacy, science knowledge, microbiology texts

INTRODUCTION

Reading comprehension of scientific texts is a well-recognized, powerful vehicle for engaging students' minds and helping them construct scientific inquiry habits, reach a deep conceptual understanding, and attain science achievements (Graesser et al., 2002; Krajcik and Sutherland, 2010; Pearson et al., 2010; Yore and Tippett, 2014; van Rijk et al., 2017; Sason et al., 2020). However, researchers have asserted that the mere provision of reading opportunities and strategies is often insufficient to effectively develop science literacy without explicit scaffolding to support readers' self-regulated learning (Lai et al., 2014; Murphy et al., 2017). The Programme for International Student Assessment (PISA) defines science literacy as "the ability to engage with science-related issues, and with the ideas of science as a reflective citizen" (Organisation for Economic Co-operation Development, 2015a, p. 50).

Motivation plays an important role in science students' reading by determining the extent to which students engage with science texts and persevere in applying effort, without aborting, until successfully completing the texts' accompanying reading comprehension tasks (see review by Morgan and Fuchs, 2007). Thus, when facing a reading task, students must not only attain knowledge about reading comprehension strategies such as locating ideas in text and processing and integrating information—namely, *cognitive* self-regulation skills—but also must attain knowledge about how and when to apply these different cognitive strategies—namely, *metacognitive* self-regulation skills (e.g., Schreiber, 2005; Roebers, 2017; Jian, 2018; Pamungkas et al., 2018; Farhana et al., 2020). Students must also acquire explicit strategies for self-regulating their own *motivation*—deciding how to approach the knowledge acquisition process and how much effort to invest—to cope with what may be a cognitively, emotionally, and temporally demanding task (e.g., McClelland et al., 2007; Guthrie and Coddington, 2009; Kelley and Decker, 2009; Logan et al., 2011; Skibbe et al., 2011; Liew et al., 2019; Li et al., 2020).

Most prior research on learners' self-regulation in the reading context has focused on supporting the cognitive and metacognitive aspects of self-regulated learning (also see Ahmadi et al., 2013; Rastegar et al., 2017; see reviews in Ali and Razali, 2019 and Deliany and Cahyono, 2020). In contrast, the motivational aspect has been under-investigated (McNamara, 2017; Egloff, 2019; Egloff and Souvignier, 2020). Embedment of self-questions into learning material to guide students' autonomous or collaborative self-regulation of their own learning processes (e.g., Kramarski and Mevarech, 1997 "IMPROVE" method) has been shown effective for enhancing science and math learners' cognitive and metacognitive self-regulation as well as for promoting their academic achievements (Michalsky, 2013, 2020; Michalsky and Schechter, 2018). However, most prior research on self-questioning supports has been conducted in the context of cognitive and metacognitive self-regulation components rather than the motivational self-regulation component.

At the focus of the current study, previous research has not yet sufficiently explored when best to specifically embed motivational scaffolding to maximize science learners' active engagement in, and comprehension of, reading tasks. Although scaffolding to support self-regulated learning processes may be implemented at different chronological phases of learning—at the forethought, performance, or retrospective self-reflection phases (Zimmerman, 1990)—little attention has been given in the empirical literature to the relative effectiveness of the before-task *vs*. during-task *vs*. after-task timeframe for delivering motivational regulation support for scientific text reading. The current study aims to narrow this gap by expanding the literature on the benefit of scaffolding for the motivational aspect of self-regulated learning in a science reading context and, in particular, on the design of its optimal conditions.

METAMOTIVATION PROCESSES FOR SCIENTIFIC TEXT READING

Motivational self-regulation, otherwise termed "metamotivation," refers to the conscious processing of monitoring and controlling one's own motivation to increase effort and persistence when completing a task or achieving a particular learning goal (McNamara, 2017; Schwinger and Otterpohl, 2017). Specifically, motivational regulation includes two main component processes: monitoring and control (Corno, 1993; Boekaerts, 1995; Kuhl, 2000; Wolters, 2003, 2011; Pintrich, 2004; Sansone and Thoman, 2005, 2006; Schwinger and Stiensmeier-Pelster, 2012). Metamotivational "monitoring" refers to self-awareness or self-evaluation of one's motivation, whereas metamotivational "control" refers to self-management and self-regulation of one's motivation and efforts (Zeidner and Stoeger, 2019), operating as reciprocal processes that form a feedback loop (Miele and Scholer, 2018).

Metamotivational monitoring refers to students' evaluation of the quantity and the intrinsic or extrinsic quality of their own motivation to achieve a goal or complete a task. In the context of science text comprehension, students must be motivated to invest effort in trying to understand the written material and in monitoring their comprehension to observe lapses in understanding (Oakhill and Cain, 2012; Dutke et al., 2016; De Smedt et al., 2020). Such monitoring includes recognizing what motivated one to read about a science topic in the first place, what decreases one's motivation, how one's current motivation can be informed by motivation in prior similar tasks, and what one still needs to monitor so as to remediate discrepancies in one's motivation to read. According to Meniado (2016), the development of science reading comprehension skills is significantly better for learners who monitor their reading motivation.

Metamotivational control refers to choosing and actively performing strategies that strengthen or shift one's motivation. Such strategies include the use of self-talk to regulate efforts and actions, environmental control efforts to establish external conditions that are more conducive to learning effectively, and "self-consequating" behaviors, where students promise themselves a reward or reinforcement after achieving their academic goal (Schwinger and Otterpohl, 2017). Students who manage their motivation while reading—by taking a more active interest in the topic, finding a personal connection to the material, trying to reduce outside distractions, and mobilizing attention to decipher difficult ideas presented in the text—have reported experiencing a more successful learning process, gaining a sense of satisfaction and enjoyment from learning, and understanding the study topics better (Kamil et al., 2008; Salinger, 2010; Schwinger and Otterpohl, 2017).

In the context of comprehending written scientific content, metamotivational monitoring can encourage students to think about (i.e., to self-evaluate) what motivates them to comprehend a text. Having identified their reasons, readers can then take actions to self-manage (i.e., control) their engagement with the task, with the aim of increasing their motivation and, in turn, their reading comprehension (Bråten et al., 2013). For example, Azhari (2020) has recently reported that monitoring of reading motivation is a driving factor that encourages students to manage and meet their expressed goals. The experiments of Nguyen et al. (2019) have also demonstrated that, to manage motivational states effectively, students must at minimum possess self-awareness or self-evaluation about which states would be more/less advantageous for a particular task and how to produce them.

Thus, to promote students' reading comprehension and achievements, researchers have strongly underscored the importance of explicitly training students to both monitor and regulate their own motivational processes (Reynolds, 2017; Schwinger and Otterpohl, 2017). However, prior research has not yet sufficiently investigated when best to embed explicit metamotivational scaffolding to enhance learners' active, effective engagement with science reading comprehension tasks and to promote their science literacy.

TIMING OF METAMOTIVATIONAL SELF-QUESTIONING SUPPORT

Schon (1996) distinguishes between *in-action* and *on-action* reflective self-questioning. *Reflection-in-action* describes interaction with a "live" problem as it unfolds during task performance—also termed by Raelin (2001) as "contemporaneous reflection," occurring at the moment. *Reflection-on-action* describes activation of reflection processes after task performance, which enables learners to construct and evaluate explicit theories of action for solving future scientific problems—termed by Raelin (2001) as "retrospective reflection" for looking back at the experience. According to Seibert (1999), students tend to deal with live problems spontaneously, using their tacit knowledge, even when problems elicit uncertainty or surprise; hence, at the in-action (during-task) phase, reflection processes are generally not activated. In contrast, on-action (after-task) reflection processes are activated whenever a problem contains ambiguity or conflict because learners must consciously confront their tacit theories of action to evaluate their problem solution.

While Schon's work is highly regarded, it does not refer to the activation of before-action reflection processes (Hackett, 2001). *Reflection-before-action* has been described as a "pre-reflection" stage (Dewey, 1997) or as "anticipatory reflection," often occurring at the planning stage (Raelin, 2001). In pre-task reflection, teachers may provide students with self-directed questions that give external structure to the self-regulation process in the form of a general work routine.

Researchers have begun to construct innovative instructional methods for science students based on metamotivational reflection as supported by self-directed questioning (Puteh and Ibrahim, 2010; Salinger, 2010; Schwinger and Stiensmeier-Pelster, 2012; Bråten et al., 2013; Michalsky, 2013; Frankel, 2016). However, empirical studies to date have not yet simultaneously compared the three possible metamotivational scaffolding timeframes corresponding with the forethought, performance, and retrospection phases of self-regulated learning of Zimmerman (1990).

Research to date examining before-task scaffolding for self-regulated learning, delivered only at the reflection-before-action phase (per Dewey, 1997; Raelin, 2001), has not sufficiently investigated science reading or scaffolding that specifically focused on metamotivation. In the math and literature learning contexts, pre-task scaffolding given to high-school students to support their cognitive and metacognitive (but not motivational) self-regulated learning (i.e., before math problem solving or literature reading comprehension) has been found to promote learners' motivation to perform the task as well as their academic-domain achievements (Mevarech and Kramarski, 2017; Reynolds, 2017). These findings for before-task cognitive and metacognitive scaffolding suggest the possible benefits of pre-action self-questioning of a metamotivational nature. Scholer and Miele (2016) have recommended using metamotivation processes before the learning action to enhance learners' fuller engagement in tasks and higher self-efficacy for successfully activating cognitive processes, compared with conditions where metamotivation is used during and or after cognitive processes.

Little research has examined the efficacy of retrospective metamotivational self-questioning in the form of instructional scaffolding presented to learners only after completing their task (reflection-on-action per Schon, 1996). In one study, Scholer and Miele (2016) have shown that scaffolding for metamotivation reflection delivered after completing a science learning task improves university students' achievements, compared with students who do not receive such scaffolding.

With regard to during-task scaffolding, delivered only at the reflection-in-action phase (per Schon, 1996), comparative research has shown that high school students exposed to metamotivational self-questioning instructional methods during their reading of microbiology texts significantly outperform their peers who do not receive metamotivational self-questioning support, as assessed on measures of general science literacy and domain-specific microbiology knowledge (du Boulay, 2011; Mahdavi and Tensfeldt, 2013; Michalsky, 2013).

In one of the rare studies to date comparing the three timeframes for self-regulatory scaffolding of reading comprehension, Michalsky (2013) has presented IMPROVE self-questions to elementary school students before, during, and after reading science texts (albeit addressing metacognitive regulation, not motivational regulation). Findings have indicated that these younger children perform best when they receive the metacognitive self-questioning after their text reading, as assessed by measures of general and domain-specific science achievements and metacognitive awareness. Prior research has also shown improvements in all three components of self-regulation [cognition, metacognition, and motivation as assessed using the measure of Pintrich (1999)] when secondary school students adapt their trained reading methods to a specific text *via* the use of a preplanned external procedure that helps structure students' processes of cognitive and metacognitive (but not motivational) self-regulation as implemented before, during, and after the reading task (Souvignier and Mokhlesgerami, 2006).

CURRENT STUDY OBJECTIVES

In line with the call of Lajoie (2005) to examine not only what and how to scaffold for reading comprehension but also when to scaffold and when to fade scaffolding, the current study's preliminary exploration aims to narrow the gaps mentioned earlier in the literature. The present quasi-experiment compared the effectiveness of the three timeframes for introducing metamotivational self-questioning support—before, during, or immediately after reading scientific texts—as compared with a control group receiving no metamotivational support at all. To comprehensively assess the impact of the four different intervention conditions, gains were measured in general science literacy, domain-specific knowledge, and metamotivational skills following the intervention.

This study focused on 10th graders because, during adolescence, students' engagement in and motivation for reading decrease (Wigfield et al., 2016). Specifically, with regard to the field of science literacy, students often report a strong dislike of reading, which may be attributed to age-related decreases in self-efficacy beliefs about their adequacy of skills and knowledge for comprehending increasingly complex secondary school science texts (Guthrie and Coddington, 2009; Cunningham and Zibulsky, 2014).

Based on prior literature indicating that supporting students' motivation for reading enhances scientific text comprehension (e.g., Scholer and Miele, 2016; Reynolds, 2017), all three metamotivational groups were expected to outperform the control group on all three dependent variables. Due to the paucity mentioned earlier of comparative research regarding the timing of metamotivational scaffolding for secondary students' scientific text comprehension (see, for example, rare studies on motivation and cognition aspects by Souvignier and Mokhlesgerami, 2006; Logan et al., 2011), no explicit assumption was formulated about the effects of the "before" vs. "during" vs. "after" metamotivational scaffolding approaches embedded at three different phases of the scientific text reading.

METHOD

Participants

Participants were 202 10th graders (102 boys, 100 girls; mean age: 15.5 years, $SD = 0.63$) who attended eight heterogeneous classes belonging to different districts. The classes were randomly selected from 21 Israeli high schools whose science teachers participated in a long-term 4-months in-service training program concerning the 10th-grade *Invitation to Scientific Inquiry* science curriculum. The following parameters were similar across all high schools: size (two to three classes per grade level for grades 7–12), middle-class socioeconomic status as defined by the Israel Ministry of Education (Central Bureau of Statistics, 2006), and students' pretest science achievement levels.

The eight teachers who underwent the current training and delivered the intervention to their 10th-grade science classes (five females, three males; mean age: 35 years, $SD = 0.82$) held a science teaching certification, an academic degree in science, and more than 8 years of experience in science teaching. Two teachers each were randomly assigned to the four intervention conditions: those receiving metamotivational self-questioning support before text reading ("BEF," $n = 52$), during text reading ("DUR," $n = 50$), or after text reading ("AFT," $n = 54$), and those who did not receive any self-questioning or metamotivational support ("control," $n = 46$). Statistical analyses conducted at pretest on demographic variables for teachers (sex, age, and years of teaching experience) and students (sex and age) and on all study variables for students yielded no statistically significant intergroup differences.

SCIENCE STUDY UNIT

All students in all eight classrooms studied the "The World of Microorganisms" study unit for 3.5 months during 10th grade as part of a series of science study units entitled *Invitation to Scientific Inquiry* (National Research Council, 2015). All eight classrooms used the same textbook and read the exact same scientific texts comprising the inquiry-based "Microbiology" unit for three lessons per week over 14 weeks. The experiment was delivered in six of the eight classrooms, in only one of their three weekly microbiology lessons. Once weekly, the six teachers in the "BEF," "DUR," and "AFT" groups (two teachers per group) implemented their assigned metamotivational self-questioning scaffolding method for their 10th graders' reading comprehension of scientific texts, whereas the two teachers in the control condition used traditional instruction for all three weekly lessons.

For the first 2 weeks of the 14-weeks period, the two classrooms comprising the control group introduced standard instructional methods for scientific text comprehension, with no metamotivational scaffolding. In the remaining six of the eight classrooms, the teachers in the three experimental groups dedicated their first two weekly lessons to introducing their assigned IMPROVE self-questioning model (BEF, DUR, or AFT) that students would utilize before, during, or after reading scientific texts, respectively. During these two introductory training lessons, the instructors in the three experimental groups provided demonstrations and modeling of their respective metamotivational scaffolding conditions to initially train students in the utilization of these scaffolds for attempts to monitor and manage their motivation and efforts.

For all four learning conditions, each of the remaining 12 lessons contained three parts: outline, practice, and summary phases (see **Appendix A**). In the practice phase that comprised most of each lesson (∼30 min), all students practiced comprehension of the lesson's scientific texts and, based on their reading, worked to solve related scientific exercises. Each student in all four groups received a personal copy of the printed worksheet presenting that lesson's microbiology text and accompanying exercises. The scientific texts were related to the microbiology phenomena that all students were learning in their other two weekly classes. For the three treatment conditions only, the worksheets additionally presented the metamotivational scaffolds, differing between the BEF, DUR, and AFT groups only in the timing of their embedment.

As shown in **Table 1**, for all four groups, each round of engagement with a science reading comprehension task comprised two phases: (a) individual reading and individual exercise performance, followed by (b) small-group discussion and joint reflection on the individual students' exercise solutions. Only in the BEF/DUR/AFT conditions (but not in the control condition) did students receive and respond to metamotivational training scaffolds during these two engagement phases.

THREE EXPERIMENTAL METAMOTIVATIONAL TREATMENT CONDITIONS

Students in the three experimental conditions (BEF, DUR, and AFT) were all exposed to the same series of four self-addressed metamotivation questions, based on the IMPROVE method of Kramarski and Mevarech (1997) as updated by Michalsky (2013). These four self-questioning scaffolds for each microbiology reading comprehension task pertained to Comprehension (task knowledge), Connection (inter-task knowledge), Strategies (strategy knowledge), and Reflection (self-knowledge). The three experimental training groups' metamotivational scaffolds differed from one another only in (a) the timing of their embedment in the worksheets (e.g., see **Appendix B** for the DUR group) and (b) their use of appropriate tense: future tense for the BEF group, present tense for the DUR group, and past and future tense for the AFT group (see left column of **Table 2**).

During the two introductory training lessons (Lessons 1 and 2), the instructors in the three experimental groups demonstrated to students how to utilize the four IMPROVE self-questioning scaffolds throughout their individual and small-group phases of engagement with the study unit's assigned science texts and to accompany reading comprehension exercises, according to each condition's timing for embedment (see **Table 1**).

During reading task practice for the experimental conditions in Lessons 3–14, the individual engagement phase was accompanied by an individual responding to the four metamotivational self-questioning scaffolds (see **Table 2** for excerpts from students' utilization of these training scaffolds in the individual phase). Then, the small-group engagement phase in the three groups was accompanied by joint discussion and reflection on their metamotivational responses.

To be noted, the Comprehension, Connection, and Reflection self-questions scaffolded students' motivational monitoring or awareness, whereas the Strategy question uniquely scaffolded students' attempts to control and manage their motivation and efforts. Thus, to scaffold the training procedure for the Strategy question in each lesson, each student in all three treatment conditions also received a personal copy of a user-friendly printed card cueing them about the repertoire of eight possible strategies for managing their own motivation (e.g., how to apply self-talk in their science reading task; see left column of **Table 3**). The instructor had modeled and exemplified these eight motivational management strategies in Lessons 1 and 2, based on Schwinger and Otterpohl (2017), according to each condition's timing for the Strategy self-question. Each treatment condition's worksheets and cards were included in the teachers' guidebook.

TEACHER TRAINING

To prevent treatment diffusion and compensatory rivalry, each pair of teachers (in the BEF, DUR, AFT, and control conditions) participated in a separate 2-days (6-h) in-service training program on the instruction of scientific text comprehension. The training instructor (the author) holds expertise in science text reading comprehension and the different metamotivational support conditions.

The first day of training was the same for all four conditions (BEF, DUR, AFT, and control), emphasizing the importance of strengthening students' science literacy and discussing the possible difficulties students encounter in comprehending scientific texts. The second day differed according to the assigned condition. The two teachers in the control group received the standard national 10th-grade approaches for reading science texts relevant to the study unit, and the instructor demonstrated teaching methods for enhancing scientific text comprehension in the classroom. Each of the three metamotivational conditions (two teachers each) received an introduction to the rationale and techniques of their assigned IMPROVE scaffolding method (BEF, DUR, or AFT). For these six teachers, the instructor accentuated the importance of metamotivation for encouraging scientific text reading, demonstrated the assigned timing and procedure for the IMPROVE self-questions' implementation in the classroom, and also modeled the use of the eight motivational management strategies based on Schwinger and Otterpohl (2017).

Throughout both days of training for all eight teachers, the instructor strongly emphasized the benefit of encouraging students to initiate discourse with their small-group team members through instructions such as: "Discuss your scientific ideas and reasoning with your team" or "Explain your answers to your peers."

FIDELITY

To ensure teachers' adherence to the scaffolding methods, all eight classrooms were observed by the author every other week across the 12-weeks experiment (8 classes $\times$ 6 observations = 48 observations in total). For the three treatment conditions (BEF, DUR, and AFT), observations were conducted in the one weekly biology lesson (out of three) when the teachers applied their assigned metamotivational scaffolding. For the control group, the observed lessons were selected randomly. After every observation, the instructor gave feedback to each observed teacher, answered teachers' questions, and offered recommendations for improvement if necessary. Overall, the

TABLE 1 | Four groups' training conditions (Modeled in lessons 1 and 2 and practiced in lessons 3 and 14).

	Lesson phase	Treatment groups			Control group
		BEF: Before reading ($n = 52$)	**DUR: During reading ($n = 50$)**	**AFT: After reading ($n = 54$)**	
Training procedure	A. Individual work	1. Self-questions 2. Text reading & exercises	Text reading & exercises, alternating with self-questions	1. Text reading & exercises 2. Self-questions	Text reading & exercises
	B. Small-group discussion	1. Self-questions 2. Exercises	Exercises, alternating with self-questions	1. Exercises 2. Self-questions	Exercises
General focus of responses to self-questions during training		Expectations about anticipated text/topic, not associated with a specific case	Specific difficulties or successes arising from the experience	The global experience and less so to the details	Not applicable

"Self-questions," for the three treatment groups only, included: (1) four IMPROVE metamotivation self-questions on Comprehension, Connection, Strategy, and Reflection, embedded into printed worksheets according to conditions' timing, to scaffold the microbiology text reading and its accompanying comprehension exercises; and (2) a printed card cueing eight-strategy metamotivation management repertoire to support the Strategy self-question.

teachers adhered well to the training they had received, both (a) regarding the microbiology unit's correlation to the standard national science curriculum and pedagogic inquiry strategies and (b) regarding their assigned scaffolding approach (or none) for reading scientific texts.

ASSESSMENT MEASURES

Three measurements were each completed by students at the pretest and posttest intervals.

Domain-Specific Microbiology Test

This 22-item domain-specific test was designed by the National Science Committee of the Israel Ministry of Education (2015) to examine students' knowledge of "The World of Microorganisms" science curriculum. The test included 10 multiple-choice items such as "Which of these statements is not true about HIV?" giving the following four choices [the correct response is "c"]: (a) It has a long incubation time, causing it to be able to remain in the host for a long time before discovery; (b) It is a retrovirus; (c) It infects all human cells; (d) There is a high rate of mutation in the HIV virus. Each of the 10 multiple-choice items was scored as either 0 (incorrect) or 4 (correct), with the total score for these items ranging from 0 to 40.

The scoring for each of the test's 12 open-ended questions (e.g., "Write two viruses' characteristics") ranged from 0 (incorrect) to 5 (full answer), with the total score for all open-ended questions ranging from 0 to 60. Two trained judges with expertise in science knowledge coded students' responses. Inter-judge reliability, calculated for the same 35% of the responses coded by both judges, yielded reliability coefficients ranging from $r = 0.88$ to 0.97 for all levels. Total microbiology scores were 0–100. The correlation between the pretest and posttest scores was $r = 0.81$.

General Test of Science Literacy

This 15-item test was designed for the purpose of the current study based on PISA 2015 science literacy tests (Organisation for Economic Co-operation Development, 2017), tapping into students' "literacy" in the five major components of scientific experiments (see **Table 4**). Two trained judges with expertise in science knowledge coded students' responses. Inter-judge reliability, calculated for the same 40% of the responses coded by both judges, yielded reliability coefficients ranging from $r = 0.81$ to 0.93 for all levels. Total general literacy scores were 0–100. The correlation between the pretest and posttest scores was $r = 0.85$.

Motivational Regulation Strategies in Reading Science Texts

Students' self-reported use of metamotivational management efforts was assessed using the 30-item Motivational Regulation Strategies Questionnaire of Schwinger et al. (2009), adapted to the specific context of reading scientific literature. Sample items and reliabilities for the eight different motivational regulation strategies are presented in **Table 3**.

PROCEDURE

The research reported in this study involving human participants was approved by the Research Ethics Board at Bar-Ilan University in accordance with ethical standards comparable to the 1964 Helsinki declaration. The eight participating teachers in the current study were randomly selected from 21 teachers who volunteered for further training and research on scientific text comprehension, following their participation in the *Invitation to Scientific Inquiry* in-service training program held in central Israel. The eight teachers were then randomly assigned to one of the four intervention conditions (two teachers each to the BEF, DUR, AFT, and control conditions). The purpose of the study and the existence of the other intervention conditions were masked; teachers were only informed by the training instructor that they were participating in an experiment on new pedagogical approaches to enhance scientific text comprehension.

All students were administered the three pretests (on science literacy, domain-specific microbiology knowledge, and motivational regulation strategies for reading science texts) during their biology lessons within the first 3 weeks of the

TABLE 2 | IMPROVE metamotivational self-questions, with sample excerpts from individual phase of student training lessons, by treatment group.

IMPROVE metamotivational self-questions	Excerpts from individual metamotivational practicing by experimental group		
	BEF: Before reading ($n = 52$)	**DUR: During reading ($n = 50$)**	**AFT: After reading ($n = 54$)**
Comprehension (task knowledge) State and explain: What will motivate/is motivating/motivated your performance of the scientific text reading and comprehension exercises? Why? Please explain your reasoning. When running into difficulties, what will you do?	• Knowing that the exercise will help me understand much better what we are learning in class with the teacher. • I've long been interested in science topics. • I've always wondered how HIV infects people and why it's so dangerous.	• Trying to answer the questions about the virus life cycle successfully. • The truth is, I don't know why I have to read this difficult text on sterilized rats. Low motivation.	• It really helped me to understand more thoroughly what we learned in class. • It was really interesting. • I had no motivation at all.
Connection (inter-task knowledge) What will be/are/were the similarities and differences between your motivation and efforts in the reading and comprehension exercises at hand compared to those you have solved in the past?	• Because I read about bacteria before, I think this text will be easier for me. • I have never heard about this subject, so it looks interesting.	• There are a lot of concepts and ideas that are not familiar to me, so it is lowering my motivation. Why isn't it easier? • This time I made a flowchart of what I am reading, so it's giving me a good feeling and helping me gain a lot of motivation.	• This time I was less motivated because the topic wasn't that interesting for me. • I arrived with less motivation but was very surprised that I was able to understand. In the previous task, the topic was very promising, but I was bored. This time the opposite happened. In the end, it was interesting.
Strategies (strategy knowledge) What strategies from the repertoire you learned in class or which other strategies do you plan to use/are you using/did you use in performing the reading and comprehension exercises? Why? (Use your printed card cueing the eight-strategy metamotivation management repertoire)	• I will remind myself that in the end, we have a common task that needs to be solved together. • I will tell myself not to give up on putting in more effort because I will then be able to answer the questions at the end and succeed in the sciences.	• I read the whole part on the mechanism of bacterial resistance to antibiotics, sentence by sentence because it is important for me to succeed in answering the questions at the end. • I just skip the hard vocabulary words about the biological lifecycle of the virus at first, so I do not have to stop reading. I will go back to them at the end.	• I constantly read out loud to myself to stay focused, so I could succeed later when everyone answered the questions in the team. And I also talked to myself, so I could get a high grade. • I saw that everyone was reading, so I realized that this is a text that can be managed alone and that I would be able to succeed and not be left behind.
Reflection (self-knowledge) Do you feel good about your motivation and efforts for the reading and comprehension exercises that you are going to perform/are performing/performed? Explain.	• I am not sure… But I am beginning to convince myself that it is important for my success in school. • I am going in with a positive attitude to reading this text.	• I lose a lot of my motivation because I run into difficulties and can't read fluently. So how can I get motivated in this kind of situation? • I am satisfied with my level of motivation to persevere in the task. I can raise my motivation if I think about my future success in the science field.	• I had a lot of motivation to read because I finally understood what probiotics are, and I have to remember that there are a lot of topics that if you do not start to delve into them, then you would not really understand and would not enjoy them. • I lost motivation in the middle because I remembered we had a science test tomorrow. Just a shame I didn't concentrate on the task. I should have told myself that the more I concentrate, the more I will succeed on the test tomorrow.

school year, immediately before beginning the 3-months "The Microorganisms' World" science learning unit. At the end of the 3-months unit, all students completed the three measures again in their biology classrooms (posttests).

DATA ANALYSES

One-way within-subject analyses of variance (ANOVA) with repeated measures were conducted, with treatment (four groups) as the independent variable and with posttest performance measures (for the three tests separately) as the dependent variables. Analyses of the total scores were followed by analyses of component subscales. *Post hoc* comparisons were conducted as needed in the form of pairwise contrasts. In addition, correlations were calculated among the three dependent variables at the end of the study (Time 2) for each of the four research groups.

RESULTS

Domain-Specific Science Knowledge Test on Microbiology

Table 5 presents the means, standard deviations, and adjusted means for students' total scores on the Test of Science Knowledge by time and treatment. As seen on the table, at pretest, no significant differences emerged between the treatment groups with regard to microbiology knowledge, $F_{(1,201)} = 13.56$, $\eta^2 = 0.19$, $p > 0.18$. This validated the four groups' equivalent baseline scores for microbiology knowledge. The one-way repeated

TABLE 3 | Repertoire of eight motivational management strategies.

	Strategy[a]	Motivational regulation strategies questionnaire (Schwinger et al., 2009)		
		No. of items	**Cronbach α**	**Sample items**
1	Enhancement of personal significance	3	0.75	I strive to relate the scientific text to my own experiences
2	Mastery self-talk	4	0.83	I persuade myself to keep on reading to find out how much I can read scientific text successfully
3	Enhancement of situational interest	5	0.86	I make reading scientific text more pleasant for me by trying to arrange it playfully
4	Performance-approach self-talk	5	0.80	I call my attention to the fact of how important it is to obtain good grades
5	Performance-avoidance self-talk	3	0.87	I imagine that my classmates make fun of my poor performance
6	Environmental control	4	0.79	Before beginning with work, I strive to eliminate all possible distractions
7	Self-consequating	3	0.77	I make a deal with myself, saying that I will do something pleasant after I finish work
8	Proximal goal setting	3	0.87	I approach work step-by-step in order to get the feeling that I am progressing well
	Total	30	0.84	

[a]*Strategies listed in left column were presented on a printed card to each student in three treatment groups throughout training procedure, cueing eight-strategy metamotivation management repertoire to scaffold IMPROVE Strategy self-question.*

measures ANOVA revealed a significant main effect for Time, $MS_e = 5.3$, $F_{(1,201)} = 11.3$, $\eta^2 = 0.36$, $p < 0.001$, and a significant Time × Treatment interaction, $F_{(1,201)} = 31.2$, $\eta^2 = 0.15$, $p < 0.001$. However, at the posttest interval, significant intergroup differences did emerge. *Post hoc* analyses of the adjusted mean scores based on pairwise comparison *t*-tests indicated that the BEF group ($M = 78.31$) significantly outperformed all other groups; the AFT group ($M = 70.32$) significantly outperformed the DUR group ($M = 74.11$); and the control group ($M = 65.17$) attained the significantly lowest microbiology knowledge scores (all $p < 0.05$).

General Science Literacy

Table 6 presents the means, standard deviations, and adjusted means for students' total scores and subscale scores on the Test of Science Literacy by time and treatment. At pretest, no significant differences emerged between the treatment groups regarding the total score or any of the five components of general science literacy, $F_{(1,201)} = 18.32$, $\eta^2 = 0.13$, $p > 0.22$. This validated the four groups' equivalent baseline scores for general science literacy. As presented on the table, the one-way repeated measures ANOVAs revealed a significant main effect for Time and a significant Time × Treatment interaction for the total score, $MS_e = 25.16$, $p < 0.001$, and for all five of the literacy components, $MS_e = 28.36$, $p < 0.001$. As illustrated in **Figure 1**, *post hoc* analyses of the adjusted mean scores based on the pairwise comparison *t*-test indicated that on the total score, the BEF group ($M = 74.98$) significantly outperformed all other groups; the AFT research group ($M = 62.96$) significantly outperformed the DUR group ($M = 67.84$); and the control group ($M = 58.98$) attained the significantly lowest mean literacy scores (all $p < 0.05$). As seen in the figure, the same pattern of findings emerged for all five science literacy components.

Motivational Regulation Strategies for Science Text Reading

Table 7 presents the means, standard deviations, and adjusted means for students' total scores and eight strategy scores on the Motivational Regulation Strategies Test, by time and treatment. At pretest, no significant differences emerged between the treatment groups regarding the total score or any of the eight strategies, $F_{(1,201)} = 18.63$, $\eta^2 = 0.23$, $p > 0.24$. This validated the four groups' equivalent baseline scores on motivational regulation strategies. As presented in the table, the one-way repeated measures ANOVAs revealed a significant main effect for Time and a significant Time × Treatment interaction for the total score, $MS_e = 36.12$, $p < 0.001$, and for all eight motivational management strategies, $MS_e = 23.25$, $p < 0.001$. *Post hoc* analyses of the adjusted mean scores based on the pairwise comparison *t*-test indicated that on the total score, the BEF group ($M = 4.12$) significantly outperformed all other groups; the AFT group ($M = 3.24$) significantly outperformed the DUR group ($M = 3.77$); and the control group ($M = 2.91$) attained the significantly lowest mean scores in motivational regulation (all $p < 0.001$). As seen in **Table 7**, the same pattern of findings emerged for all eight strategies.

Correlations Among Dependent Variables at Time 2

Table 8 presents the results of the correlation analysis conducted among science literacy, domain-specific microbiology knowledge, and metamotivation regulation strategies for each of the four research groups at the end of the study. Significantly higher correlations (using Fisher's transformation of *r* to *Z*) were found in the BEF group than in the other three groups. The AFT group revealed significantly higher correlations than the DUR group. The control group showed the lowest correlations among dependent variables, which were all non-significant.

DISCUSSION

Findings from the current quasi-experiment clearly highlighted the advantage of metamotivational scaffolding's embedment in 10th-graders' scientific text reading over the effectiveness of standard instructional methods that do not include any such scaffolding. Namely, as expected, all three student groups who

TABLE 4 | Sample items for five components on 15-item general test of science literacy.

Literacy component	Sample from two closed multiple-choice items: Scored either 0 (incorrect) or 7 (correct)	One open-ended item: Scored either 0 (incorrect) or 6 (full answer)	Cronbach α
Describing phenomena	Bacteria do not develop in honey. Why? (a) Bacteria do not like sweets. (b) Viscosity of the honey does not allow colonies to be created. (c) Honey does not contain nutrients for bacteria. (d) (correct answer) Bacteria dry out and die.	After the experiments conducted by the students in pickling cucumbers and making yogurt, Adina stopped eating olives, pickled cucumbers, and yogurt. She claimed that these products contain bacteria, and bacteria can cause disease. Introduce a counterargument that might persuade Adina to eat these products again.	0.82
Formulating hypotheses	What will happen to a small number of bacteria transferred to a closed vessel containing food and optimal temperature conditions? (a) bacteria immediately multiply at a rapid rate thanks to the abundance of food. (b) In a closed vessel, bacteria will not be able to multiply at all. (c) (correct answer) Number of bacteria will increase as long as there is enough food and oxygen. (d) Number of bacteria will increase more and more despite the pH change in the vessel.	Healthy humans' digestive system has a very large number of bacteria. Our body's immunology systems do not work against them. Why? Suggest an experiment for testing the resistance of those bacteria. Address the following issues: Formulate a hypothesis for testing the question and explain the basis for your hypothesis.	0.87
Identifying dependent variables	Researchers were asked to estimate the number of bacteria in a fixed volume of a given solution. Each researcher chose a different method to count the bacteria. In which of the following counting methods will the smallest number of bacteria be found? (a) Counting under a microscope. (b) Counting using a device that checks the degree of turbidity. (c) In all methods, the same number of bacteria will be counted. (d) (correct answer) Culturing the solution and counting colonies of bacteria.	What is the dependent variable in the suggested experiment?	0.86
Identifying independent variables	A grain of soil contains a diverse population of bacteria. If you want to increase the percentage of bacteria performing photosynthesis out of all the bacteria in the soil grain, it is advisable to transfer the soil grain to: (a) A lighted food substrate, which contains organic compounds. (b) (correct answer) Illuminated food substrate, which does not contain organic compounds. (c) A food substrate in the dark, which contains organic compounds. (d) A food substrate in the dark, which does not contain organic compounds.	What is the independent variable in the suggested experiment?	0.83
Reporting the results and drawing conclusions	Here are some facts about bacteria that occur in the process of acidification. Mark the facts that explain the cucumber pickling and yogurt making processes: (a) These bacteria are tiny creatures that have one cell and lack a nucleus. (b) These bacteria feed on organic substances found in their environment. (c) (correct answer) These bacteria carry out the process of anaerobic respiration (agitation). The decomposition products are acid and carbon dioxide. (d) These bacteria multiply in the process of division, which explains the cucumber pickling and yogurt-making processes.	Which results support your hypothesis? What conclusions can you draw from those results?	0.81
Total score range: 0–100	For closed items: 0–70	For open items: 0–30	0.84

received support for motivational self-regulation were found to outperform the control group on all studied variables: not only on their ability to regulate their own motivation to read about science but also on their general and domain-specific science achievements. With regard to the main focus of this study—identifying the optimal phase for embedding metamotivational scaffolding—high school students who received such scaffolding before the reading task significantly outperformed the other two groups who received metamotivational scaffolding either during or after reading, regarding all of the outcomes assessed in the present study. More extensive consideration is given next to these findings.

TABLE 5 | Students' means, standard deviations, and adjusted mean scores on the test of domain-specific science knowledge, by time (pre/post) and treatment.

Microbiology knowledge	Group							
	Treatment: Metamotivational scaffolding						Control: No scaffolding ($n = 46$)	
	BEF: Before reading ($n = 52$)		DUR: During reading ($n = 50$)		AFT: After reading ($n = 54$)			
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
M	46.63	78.66	49.53	70.14	47.31	74.82	47.72	66.05
(Adj. *M*)		78.31		70.32		74.11		65.17
SD	10.12	14.18	11.28	13.42	11.45	13.26	12.34	14.25

Scores ranged from 0 to 100.

TABLE 6 | Means, standard deviations, and cohen's d effect sizes[a] on general test of science literacy, by time and treatment, with significant effects.

Literacy component	Group								Significant effects ($p < 0.001$)			
	Treatment: Metamotivational scaffolding								Time		Time × Treatment interaction	
	BEF: Before reading ($n = 52$)		DUR: During reading ($n = 50$)		AFT: After reading ($n = 54$)		CON: Controls—No scaffolding ($n = 46$)					
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	$F_{(1,201)}$	η^2	$F_{(1,201)}$	η^2
DESCRIBING PHENOMENA												
M	12.11	16.65	11.92	14.86	12.35	14.21	12.23	14.35	97.12	0.41	24.17	0.47
SD	3.93	3.51	3.94	4.12	4.03	4.62	4.11	5.23				
d	1.26		0.49		0.62		0.46					
FORMULATING HYPOTHESES												
M	11.36	16.11	10.56	14.23	11.32	15.65	10.23	12.69	67.45	0.41	27.37	0.51
SD	3.13	3.21	3.41	3.32	3.61	3.42	2.91	3.12				
d	1.53		1.11		1.23		0.82					
IDENTIFYING DEPENDENT VARIABLES												
M	8.12	13.14	7.96	12.05	8.11	12.41	8.36	10.50	74.69	0.53	39.36	0.44
SD	3.42	3.51	3.93	3.91	3.52	3.44	3.71	3.81				
d	1.47		1.05		1.15		0.56					
IDENTIFYING INDEPENDENT VARIABLES												
M	8.96	14.96	8.55	12.30	9.12	13.62	9.23	11.32	145.35	0.57	64.36	0.55
SD	2.62	2.43	3.11	2.83	2.80	2.65	3.34	3.23				
d	*2.41*		1.25		1.61		0.65					
REPORTING RESULTS AND DRAWING CONCLUSIONS												
M	8.12	14.16	7.88	11.12	7.55	12.35	7.36	9.32	102.00	0.66	32.69	0.53
SD	3.82	3.74	3.73	3.75	3.12	3.14	3.13	3.23				
d	1.90		0.90		1.54		0.62					
TOTAL FOR SCIENCE LITERACY												
M	48.67	74.98	47.34	62.96	47.08	67.84	47.41	58.98	112.32	0.42	35.63	0.38
SD	8.12	8.31	7.31	7.17	8.53	8.22	8.43	8.51				
d	3.22		2.03		2.51		1.43					

Scores ranged from 0 to 20 for each of the five components and from 0 to 100 for the total. Significant differences emerged for all five components ($p < 0.001$): BEF > AFT, DUR, CON; AFT > DUR, CON; DUR > CON.

[a] Cohen's d effect size was calculated as the ratio between the posttest minus the pretest value and the average standard deviation of the pretest.

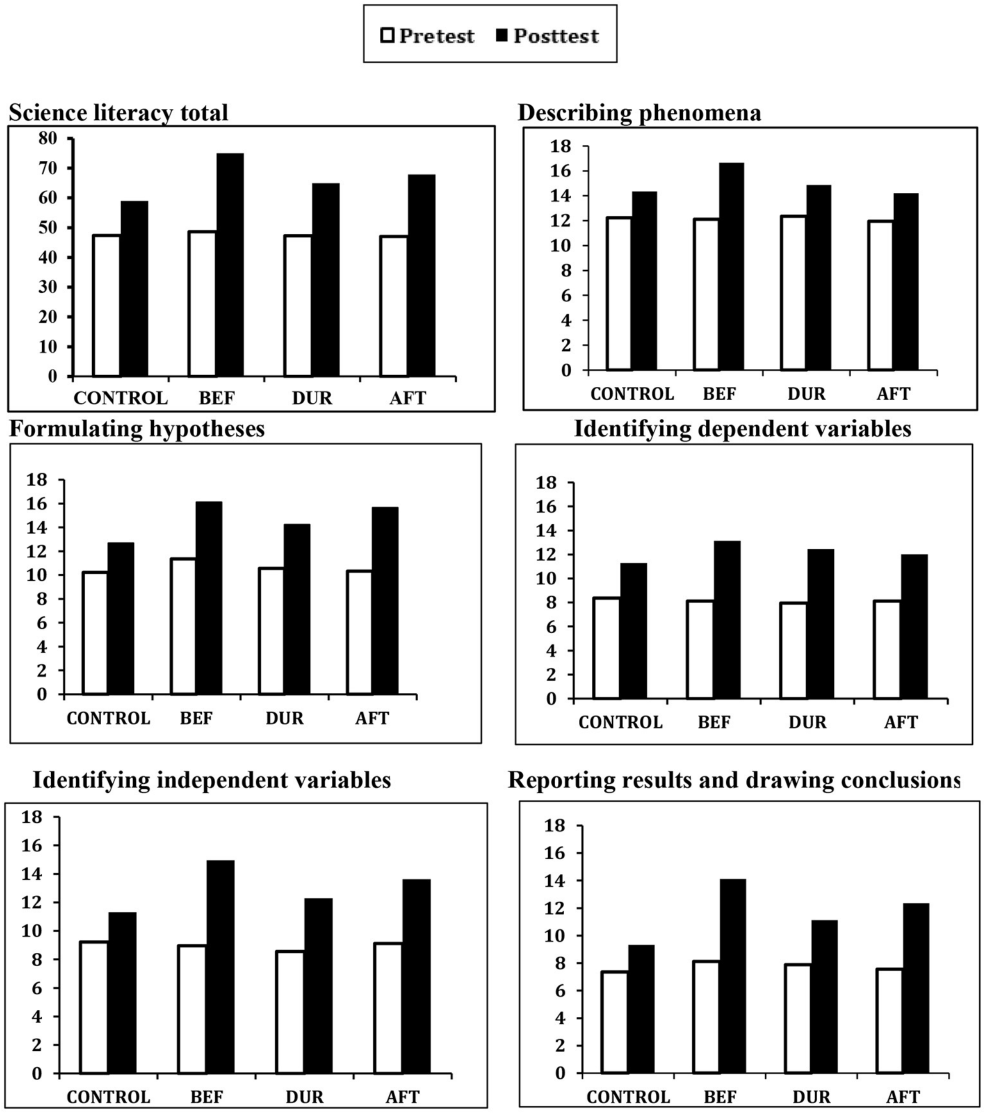

FIGURE 1 | Mean scores on science literacy total and components, by time and treatment. BEF = metamotivation intervention before text reading; DUR = metamotivation intervention during text reading; AFT = metamotivation intervention after text reading; Control = no metamotivation intervention.

Benefit of Metamotivational Scaffolding Over Standard Instruction

The advantage found for metamotivational scaffolding (in the BEF, DUR, and AFT groups) over standard instructional methods (in the control group) coincides with prior studies showing that explicit scaffolding is a necessity when training students to self-regulate their motivation while reading scientific texts (Souvignier and Mokhlesgerami, 2006; Michalsky, 2013; Hsu et al., 2016; McNamara, 2017). This outcome also substantiates the claim that mere exposure to scientific texts is insufficient on its own (Ozuru et al., 2009). As Hartman (2001, p. 56) has argued [emphasis appeared in the original]:

> Teachers should not be satisfied with putting students in situations which require them to use any strategy they want students to use. **Practice isn't enough**. It is also important to provide explicit instruction in **when, why and how** to use the strategy; students need to understand the rationale and effective procedures for the strategy so that they can recognize appropriate contexts for its use, so that they have criteria for evaluating their strategy, and so they can self-regulate its use.

The three treatment groups' higher gains in motivational self-regulation than the control group may be attributed to the reflective processes inherent in answering the self-addressed metamotivation questions. Namely, contemplating the Comprehension, Connection, and Reflection self-questions may have promoted students' self-awareness of their own motivation, whereas contemplating the Strategy self-question and cued repertoire of strategies may have promoted their

TABLE 7 | Means, standard deviations, and cohen's d effect sizes[a] of motivational regulation strategies, by time and treatment, with significant effects.

Self-regulation strategy	Treatment group: Metamotivational scaffolding						Controls—		Significant effects ($p < 0.001$)			
	BEF: Before reading ($n = 52$)		DUR: During reading ($n = 50$)		AFT: After reading ($n = 54$)		CON: No scaffolding ($n = 46$)		Time		Time × Treatment interaction	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	$F_{(1,201)}$	η^2	$F_{(1,201)}$	η^2
ENHANCEMENT OF SITUATIONAL INTEREST												
M	3.12	4.64	2.92	3.44	3.04	3.92	2.91	3.52	74.37	0.55	32.14	0.43
SD	1.34	1.51	1.32	1.42	1.33	1.32	1.21	1.22				
d	1.15		0.38		0.69		0.46					
ENHANCEMENT OF PERSONAL SIGNIFICANCE												
M	2.61	3.92	2.71	3.03	2.54	3.51	2.60	3.11	91.36	0.52	43.12	0.29
SD	1.32	1.52	1.24	1.41	1.62	1.53	1.41	1.32				
d	1.00		0.25		0.62		0.35					
MASTERY SELF-TALK												
M	3.52	4.73	3.24	4.01	3.42	4.55	3.32	3.81	84.39	0.33	47.39	0.56
SD	1.41	1.52	1.23	1.32	1.34	1.44	1.36	1.51				
d	0.85		0.66		0.84		0.38					
PERFORMANCE-APPROACH SELF-TALK												
M	2.51	3.62	2.22	3.04	2.44	3.45	2.33	2.82	125.13	0.41	52.39	0.52
SD	1.45	1.94	1.23	1.94	1.32	1.83	1.32	1.74				
d	0.78		0.66		0.76		0.38					
PERFORMANCE-AVOIDANCE SELF-TALK												
M	2.43	3.82	2.67	3.38	2.54	3.45	2.31	2.82	98.12	0.55	47.63	0.42
SD	1.21	1.43	1.51	1.31	1.37	1.34	1.36	1.44				
d	1.16		0.90		0.69		0.38					
SELF-CONSEQUATING												
M	2.42	4.13	2.24	3.03	2.21	3.44	2.33	2.82	144.19	0.49	44.35	0.52
SD	1.42	1.51	1.23	1.31	1.34	1.42	1.33	1.52				
d	1.21		0.94		1.21		0.38					
ENVIRONMENTAL CONTROL												
M	2.23	3.92	2.44	3.43	2.41	3.62	2.34	2.85	122.32	0.47	51.36	0.52
SD	1.32	1.41	1.23	1.22	1.31	1.41	1.46	1.55				
d	1.30		0.83		0.92		0.35					
M	2.42	3.91	2.33	2.84	2.22	3.12	2.43	2.73	97.36	0.42	35.63	0.38
SD	1.12	1.31	1.22	1.24	1.50	1.26	1.44	1.57				
d	1.22		0.43		0.62		0.24					
TOTAL FOR MOTIVATIONAL REGULATION												
M	2.63	4.12	2.60	3.24	2.05	3.77	2.43	2.91	125.77	0.57	42.36	0.51
SD	1.12	1.31	1.24	1.25	1.51	1.48	1.41	1.50				
d	1.25		0.54		0.92		0.32					

Scores ranged from 1 to 5 for each of the eight strategies and for the total. Significant differences emerged for all eight strategies (p < 0.001): BEF > AFT,DUR,CON; AFT > DUR,CON; DUR > CON.
[a] *Cohen's d effect size was calculated as the ratio between the posttest minus the pretest value and the average standard deviation of the pretest.*

self-management of that motivation. These metamotivational monitoring and control processes (Veenman et al., 2006) may, in turn, facilitate students' science achievements.

Benefits of Metamotivational Scaffolding Given Before Science Text Engagement

The BEF group of 10th graders exposed to metamotivational scaffolding before they began reading each text and its accompanying comprehension exercises significantly outperformed the other two metamotivation groups (DUR and AFT). This advantage for the BEF group occurred, although all three treatment groups had received the same training and scaffolds (for self-regulatory motivational reflection *via* the four IMPROVE self-questions and for metamotivational management *via* the eight-strategy repertoire) at some point in their engagement with the same science texts and exercises.

This current finding on high school students differs from similar prior research outcomes focused on the metacognitive

TABLE 8 | Correlations (Fisher's transformation of r to Z) among dependent variables in the four research groups at time 2.

	General science literacy				Domain-specific microbiology achievements			
	BEF	DUR	AFT	Control	BEF	DUR	AFT	Control
Motivational regulation	0.47*	0.27	0.36*	0.16	0.55*	0.32*	0.42*	0.24
General science literacy	—	—	—	—	0.57**	0.28*	0.39*	0.24

BEF: Before reading (n = 52); DUR: During reading (n = 50); AFT: After reading (n = 54); Control: No scaffolding (n = 46).
$^*p < 0.05$. $^{**}p < 0.01$.

rather than motivational component of self-regulation among younger students (Michalsky, 2013). Further research is needed to determine if the different outcomes (highest effectiveness of pre-reading scaffolding for secondary students in the current study vs. highest effectiveness of post-reading scaffolding for elementary students in Michalsky, 2013) may possibly be attributable to factors related to students' age and/or to the metacognitive vs. metamotivation type of self-questioning scaffolding. For example, perhaps the adolescents' age-related cognitive abstraction capability or short-term working memory (Souza and Oberauer, 2016) may have enabled the high schoolers to maintain the IMPROVE self-questions in mind while engaging in their reading tasks, whereas the cognitive load may have been too heavy for those younger children who received before-task scaffolding in Michalsky (2013).

It may be speculated that answering the motivation-oriented self-questions before approaching the reading task may have served to focus the current 10th-grade BEF group's attention onto their motivational state across the entire ensuing reading context. Such initial mapping of their metamotivational monitoring may thereby have helped them to identify later when they were, or were not, experiencing an optimal motivational state for learning (Brown et al., 2016). Such better self-awareness, beginning in the starting phase of the learning task, in turn, may have fostered their ability to search for effective strategies and actions among their learned repertoire of metamotivational strategies (i.e., metamotivational control), to induce that optimal state in themselves all along with the upcoming reading task and comprehension exercises (Pintrich, 2002; Wolters, 2003; Miele and Scholer, 2018).

In addition, according to the chronological model of self-regulated learning phases of Zimmerman (2000), the "starting" forethought phase involves planning strategies such as task analysis or goal setting and is mainly influenced by learners' self-efficacy (belief in their competence, Bandura, 1977) regarding the learning task. Students with high self-efficacy have been shown to work diligently to master difficult scientific reading tasks, using their cognitive strategies productively (Zimmerman and Schunk, 2013). Perhaps, the early timing of the metamotivational self-questions in the BEF group enhances 10th-graders' optimism and confidence in their ability to cope with potential difficulties that may arise during engagement with the upcoming challenging science task. It may be that building up high self-efficacy leads, in turn, to better control over their own ensuing motivations (Butler et al., 2017). Considering self-efficacy beliefs' documented links to strategy use, self-regulation, and intrinsic motivation in the reading context (Pintrich and De Groot, 1990; Zimmerman and Schunk, 2003), researchers would do well to include self-efficacy measures in future metamotivational methodologies.

Not only the BEF group but also the AFT group outperformed the DUR group on all three dependent variables—motivational regulation strategies, general science literacy, and domain-specific science achievements. This resembled a prior finding for metacognitive scaffolding given during science text reading to elementary school students (Michalsky, 2013). Perhaps the lowest outcomes for the scaffolding provided during reading comprehension processes were attributable to learners' heavy cognitive load in this instruction condition. Bunch and Earl Lloyd (2006) have argued that cognitive load theory and cognitive load management are fundamental in reading comprehension because science texts provide large and complex amounts of information. Cognitive load theory posited that effective scaffolding facilitates learning by "directing cognitive resources toward activities that are relevant to learning rather than toward preliminaries to learning" (Chandler and Sweller, 1991, p. 294). Chandler and Sweller have noted that unnecessarily forcing learners to work with disparate sources of mutually referring information leads to ineffective scaffolding and to an increase in their cognitive load during reading. Therefore, scaffolding learners to utilize specific instructional materials before commencing their learning, as given in the current BEF group, may allow learners the freedom to employ any of the scaffolds at any time as they deem necessary to promote their understanding and solving of the problem.

The groups' patterns of correlations after the experiment—among their motivational regulation strategies, general science literacy, and domain-specific science achievements using the Fisher transformation—appear to corroborate the advantage found for the BEF reading group (showing the highest correlations) over the other three groups, followed by the AFT, DUR, and control groups, respectively. Although these correlational data do not permit assumptions about causality, stronger relationships may attest to more effective reciprocal influences between students' motivational self-regulation for science reading and their science literacy and educational achievement outcomes. Greater motivational regulation may lead to greater effort and persistence, which result in better instructional performance and *vice versa* (Bandura, 1977; Guthrie and Coddington, 2009). In this sense, the scaffolding of students' motivation at the before phase of reading science texts appears to have the greatest value for leveraging the important links between metamotivation, reading comprehension, and science achievements.

Study Limitations, Implications

As a preliminary exploration of the timing of metamotivational scaffolding, the current study requires future validation. This study's utilization of only one self-questioning method (IMPROVE) suggests that future researchers would do well to expand investigation on timing to various additional kinds of metamotivational scaffolding methods such as prompts, teacher tutoring, and so on. Likewise, the stronger benefit of metamotivational scaffolding at the before phase of microbiology text reading should be examined regarding the diverse scientific content matter and non-science domains. Future researchers may also wish to scrutinize the role played by text difficulty, domain familiarity, and prior knowledge on how students utilize metamotivational scaffolding provided at different learning phases. To further explore scaffolding methods, a fine-grain inquiry may also help identify the relative effectiveness of the different metamotivational management strategies for enhancing science students' outcomes.

Furthermore, considering that the current outcomes contradict those found for elementary school children, the same methodology should be used simultaneously with students across age groups to elucidate developmental trajectories while also examining sex differences. The present study did not show any sex differences on any of the study variables, but prior research has indicated that girls tend to outperform boys on reading comprehension, whereas boys have a distinctive advantage over girls with regard to scientific interest and literacy (e.g., Organisation for Economic Co-operation Development, 2015b). Finally, qualitative methods such as think-aloud processes rather than quantitative self-reports may help clarify metamotivation experiences, skills, and strategies at different phases of text reading.

CONCLUSIONS

Although no explicit assumptions could be formulated about the comparative effectiveness of the three timeframes due to the paucity of research in this area, the current preliminary study's outcomes highlight the potential impact of the current metamotivation instructional framework. Especially when delivered at the reflection-before-action stage for looking ahead and also at the reflection-on-action stage for looking back, metamotivational scaffolding may offer important means to promote science students' capacities and to meet the growing challenges in science teaching schoolwork.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Bar Ilan University Ramat-Gan 5290002. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.658027/full#supplementary-material

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

SYSTEMATIC REVIEW
published: 31 May 2021
doi: 10.3389/fpsyg.2021.672610

Student Engagement in Mathematics Flipped Classrooms: Implications of Journal Publications From 2011 to 2020

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *26 February 2021*
Accepted: *29 April 2021*
Published: *31 May 2021*

Citation:
Lo CK and Hew KF (2021) Student Engagement in Mathematics Flipped Classrooms: Implications of Journal Publications From 2011 to 2020. Front. Psychol. 12:672610. doi: 10.3389/fpsyg.2021.672610

Mathematics is one of the core STEM (science, technology, engineering, and mathematics) subject disciplines. Engaging students in learning mathematics helps retain students in STEM fields and thus contributes to the sustainable development of society. To increase student engagement, some mathematics instructors have redesigned their courses using the flipped classroom approach. In this review, we examined the results of comparative studies published between 2011 and 2020 to summarize the effects of this instructional approach (vs. traditional lecturing) on students' behavioral, emotional, and cognitive engagement with mathematics courses. Thirty-three articles in K–12 and higher education contexts were included for analysis. The results suggest that the use of the flipped classroom approach may increase some aspects of behavioral engagement (e.g., interaction and attention/participation), emotional engagement (e.g., course satisfaction), and cognitive engagement (e.g., understanding of mathematics). However, we discovered that several aspects (e.g., students' attendance, mathematics anxiety, and self-regulation) of student engagement have not been thoroughly explored and are worthy of further study. The results of this review have important implications for future flipped classroom practice (e.g., engaging students in solving real-world problems), and for research on student engagement (e.g., using more objective measures, such as classroom observation) in mathematics education.

Keywords: flipped classroom, flipped learning, mathematics education, literature review, systematic review

INTRODUCTION

In recent years, careers in STEM (science, technology, engineering, and mathematics) fields have been growing rapidly. It is thus important to the sustainable development of society to improve students' knowledge of STEM and to prepare human resources for STEM careers. Among the four subject disciplines, however, mathematics can be particularly frustrating (Moliner and Alegre, 2020) and can prevent students from pursuing their STEM major (Adams and Dove, 2016). For example, Gundlach et al. (2015) observed that students may have significant anxiety related to courses in statistics. Dove and Dove (2015) cautioned that negative learning experiences can lead to students avoiding mathematics and can even result in mathematics anxiety. As Van Sickle (2016) concluded, engaging students in mathematics courses can not only provide a solid foundation for their future studies but also help retain students in STEM fields.

Student engagement is important for learning, as high levels of engagement are associated with various desirable outcomes, such as higher levels of academic achievement and lower dropout rates (Fredricks et al., 2004; Terrenghi et al., 2019; Abín et al., 2020). To increase student engagement, some mathematics instructors (e.g., Wilson, 2013; Cronhjort et al., 2018; Lo and Hew, 2021) have redesigned their traditional lecture-based courses using the flipped (or inverted) classroom approach. Under this instructional approach, "events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (Lage et al., 2000, p. 32). In some mathematics flipped classrooms, instructors present basic materials before class using instructional videos (Lo et al., 2017; Yang et al., 2019). Class time can thus be freed up for more instructor–student and student–student interactions (Lo et al., 2017; Bond, 2020; Erbil, 2020).

Although the results of recent meta-analytic reviews (e.g., Lo et al., 2017; Cheng et al., 2019) generally suggest that the use of the flipped classroom approach should increase students' mathematics achievement compared to traditional lecturing, we currently know little about its effect on student engagement. To address this knowledge gap, Bond (2020) conducted a systematic review of studies of flipped classrooms in K–12 research. She found that this instructional approach overwhelmingly supported student engagement across studies. It is worth noting, however, that many of her included studies did not employ a comparative between-subjects research design (i.e., they were not quasi-experiments). Is the flipped classroom approach indeed superior to traditional lecturing in terms of student engagement? This question remains unanswered.

This review aims to summarize the effect of the flipped classroom approach on student engagement compared to traditional lecturing. We focus on mathematics, as it is one of the core STEM subject disciplines. More importantly, engaging students in learning mathematics helps retain students in STEM fields and thus contributes to the sustainable development of society. Therefore, the overarching goal of this review is to make suggestions for future practice of the flipped classroom approach and for research on student engagement in mathematics education. Using a three-dimensional (i.e., behavioral, emotional, and cognitive) model of student engagement, as defined by Fredricks et al. (2004), the following research questions (RQ1 to RQ3) are used to guide this systematic review.

RQ1: How does the flipped classroom approach influence students' behavioral engagement compared to traditional lecturing?

RQ2: How does the flipped classroom approach influence students' emotional engagement compared to traditional lecturing?

RQ3: How does the flipped classroom approach influence students' cognitive engagement compared to traditional lecturing?

DEVELOPING THE CONCEPTUAL FRAMEWORK FOR RESEARCH SYNTHESIS

The conceptual framework for the research synthesis of this review is developed in two stages. First, we define the flipped classroom approach and traditional lecturing in mathematics education. The definitions help to establish the context for this review and enhance the consistency of the selection of studies. Second, we use the work of Fredricks et al. (2004) to define the framework for student engagement. This framework can serve as a lens to analyze the results of student engagement across studies.

Traditional and Flipped Classrooms in Mathematics Education

To establish the context for this review, we first clarify the meaning of traditional and flipped classrooms. Despite the absence of an explicit definition of a traditional classroom, we can identify some common practices in mathematics education. For example, Dove and Dove (2015) described the traditional classroom as: (1) "Class primarily consists of teacher-directed lecture," (2) "Most student practice occurs outside of class and individually," and (3) "Most group work, if any, occurs outside the classroom" (p. 169). Consistent with other studies, mathematics instructors would first introduce students to course materials inside the classroom, where active learning techniques such as pair work and group discussion (e.g., Loux et al., 2016; Lo and Hew, 2020; Wang et al., 2020) are used occasionally. Students are then provided with a few in-class learning tasks, followed by homework to be done after class (e.g., DeSantis et al., 2015; Guerrero et al., 2015; Wasserman et al., 2017).

In contrast, students in mathematics flipped classrooms would first be introduced to course materials before class and then complete individual and/or group learning activities inside the classroom (Lo et al., 2017; Yang et al., 2019). It is important to note that some scholars have suggested that video lectures must always be used as the pre-class instructional medium in the flipped classroom approach (Bishop and Verleger, 2013). However, other scholars disagree. For example, He et al. (2016) commented that "qualifying instructional medium is unnecessary and unjustified" (p. 61). They supported their stand using the quasi-experimental study by Moravec et al. (2010), in which the researchers showed that the use of either pre-class videos or pre-class readings with worksheets is equally effective.

In this review, we believe that mathematics instructors would choose the best instructional medium, which may not necessarily be video, to deliver their course materials. Indeed, the Flipped Learning Network (2014) does not add such a constraint (i.e., the instructor must use video lectures before class) when defining the flipped classroom approach. Without qualifying the use of instructional medium, their definition emphasizes the instructional sequence of using the individual learning space for direct instruction (pre-class) and the resulting group learning space for interactive activities involving the application of knowledge (in-class). The definition has been used to define the flipped classroom approach in mathematics education (e.g., Heuett, 2017; Hodgson et al., 2017). Therefore, this review uses the conceptual definition offered by the Flipped Learning Network (2014) and does not impose additional constraints on instructional media or activities with respect to either pre- or in-class learning components.

Student Engagement

According to Fredricks et al. (2004), student engagement consists of three dimensions, namely behavioral, emotional, and cognitive engagement. These three dimensions cover more or less everything in educational settings, as this three-dimensional model was established through a large-scale research synthesis (see Fredricks et al., 2004 for a review). Recently, the model has been adopted in the development of the flipped classroom approach (e.g., Bond, 2020; Lo and Hew, 2021). Therefore, the work of Fredricks et al. (2004) can offer a solid foundation for the research synthesis in this review.

First, behavioral engagement is concerned with students' participation, effort, and conduct (Fredricks et al., 2004). Students with high behavioral engagement will be involved in school-related activities and make an effort to complete learning tasks (e.g., quizzes and homework). Moreover, they will follow school rules and classroom norms (i.e., positive conduct) and engage in minimal disruptive behavior. According to Bond (2020), the use of the flipped classroom approach increased students' interaction and participation because the instructors were better able to utilize their class time to create an interactive learning environment. However, some undesirable behaviors were observed in flipped classrooms, such as skipping classes and unpreparedness for pre-class learning tasks (Heuett, 2017; Lo et al., 2017; Bond, 2020). In other words, the use of the flipped classroom approach can have either a positive or a negative impact on students' behavioral engagement.

Second, emotional engagement is related to students' affective reactions (e.g., interest, satisfaction, feelings, and anxiety) and attitudes toward or value placed on learning (Fredricks et al., 2004). Ideally, instructors should create a learning environment that can induce positive feelings in students and reduce their anxiety about learning (Hernández-Barco et al., 2021). Meanwhile, the learning tasks should promote student interest in course materials. Bond (2020) found that enjoyment was a frequently mentioned finding in research on flipped classrooms in the K–12 context. Students enjoyed learning using instructional videos (e.g., Khan Academy and screencasts by their teachers). Moreover, video lecturing may reduce students' anxiety because they are able to re-watch the videos to better understand course materials before class (Bond, 2020). However, the findings from a review examining 22 studies indicated no significant difference in terms of student satisfaction in traditional and flipped classrooms (van Alten et al., 2019). Besides that, student emotional engagement in other aspects (e.g., interest) has not yet been examined.

Third, cognitive engagement is concerned with students' level of investment in learning and self-regulation (Fredricks et al., 2004). Students' investment in learning goes beyond the behavioral level and can be reflected in their preference for challenges (Connell and Wellborn, 1991). Newmann et al. (1992) further emphasized the inner psychological quality of cognitive engagement and students' psychological investment in understanding and mastering course materials instead of simply completing their learning tasks. Therefore, how students regulate (e.g., plan, monitor, and evaluate) their learning is also related to cognitive engagement (Pintrich and de Groot, 1990; Zimmerman, 1990). Bond (2020) found that some flipped classroom interventions may support students' self-efficacy and self-regulation, indicating increased cognitive engagement. However, as far as we know, no research synthesis has yet been published examining how the flipped classroom approach influences students' cognitive engagement compared to traditional lecturing.

METHOD

Search Strategies

The process for selecting relevant studies followed the preferred reporting of items for systematic reviews and meta-analyses (PRISMA) statement (Moher et al., 2009). Five electronic databases were searched: (1) Academic Search Ultimate, (2) British Education Index, (3) Education Research Complete, (4) ERIC, and (5) Web of Science. The search string with relevant keywords and Boolean operators was as follows: (flip* OR invert*) AND (class* OR learn* OR course*) AND (math* OR algebra OR trigonometry OR geometry OR calculus OR statistics). The asterisk was used as a wildcard to include most of the common expressions of the flipped classroom approach (e.g., flipped classroom, flipped learning, inverted classroom, and inverted learning) in mathematics education (i.e., general mathematics and the three major content area – algebra, calculus, and statistics), such as a flipped learning algebra course (Murphy et al., 2016) and flipping a college mathematics classroom (Amstelveen, 2019). In the search string, we did not include the word "engagement" because researchers might have focused on some relevant aspects of engagement (e.g., satisfaction), but did not explicitly use this word (Bond, 2020). The current search string could therefore retrieve all potentially relevant articles with or without using the word "engagement" in their title, abstract, and keywords. The search was run on January 7, 2021.

Inclusion and Exclusion Criteria

Empirical studies published between January 2011 and December 2020 (10 years) were reviewed. This period covered the majority of the existing flipped classroom research because few studies were published before 2012 (Lo and Hwang, 2018). To be included in this review, the studies had to focus on the use of the flipped classroom approach in mathematics education contexts, such as in teaching algebra, calculus, and statistics. As the aim of this review is to compare student engagement in traditional and flipped classrooms, the included studies should report a comparative between-subjects study. To ensure consistency, the traditional and flipped classrooms involved in the studies should satisfy the aforementioned definitions. In addition, the authors had to compare at least one aspect of student engagement (e.g., attendance and interest) under the two instructional environments. Finally, no constraints were imposed on the language of instruction or location of the studies. However, the manuscripts had to be written in English and published in a peer-reviewed journal because peer review is a useful criterion for including methodologically sound studies.

Data Extraction and Analysis

The following data were extracted from each article: (a) author(s) of the article and year of publication, (b) country of implementation, (c) course content area, (d) student level, (e) flipped classroom design, and (f) major findings concerning student engagement. Both authors independently extracted the data from the comparative studies. Any discrepancies between the data extracted were reviewed, discussed, and resolved by the authors prior to data entry and analysis.

To answer the research questions, the findings concerning student engagement were analyzed thematically. More specifically, we analyzed quantitative (e.g., surveys) and qualitative (e.g., interviews) data on participants to examine student engagement. As described in the previous section, the general framework for thematic analysis followed the three-dimensional model of student engagement defined by Fredricks et al. (2004), including behavioral engagement (RQ1), emotional engagement (RQ2), and cognitive engagement (RQ3). We examined every comparison item carefully and determined whether the item referred to behavioral, emotional, or cognitive engagement through mutual discussion. To take "Talked about the course contents with peers outside the scheduled hours" (Cronhjort et al., 2018, p. 118) as an example, we categorized this item as belonging to the theme of *interaction* under behavioral engagement. We did so because of the emphasis on students taking action (i.e., behavioral engagement) in exchanging ideas with their classmates.

Ideally, the quantitative results across studies should be summarized using a meta-analytic approach. However, the complex nature of student engagement and the diversity of ways to measure it hindered our attempt to conduct a meta-analysis of the included studies, as Bond (2020) also noted previously. Therefore, following Quin (2017), we calculated effect sizes to determine the strength of the experimental effect when sufficient data (e.g., mean and standard deviation) were reported. The following formulas, as provided by Cohen (1988), were used.

$$\textbf{Cohen's } d = \frac{M_{FC} - M_{TC}}{SD_{pooled}}$$

where

$$SD_{pooled} = \sqrt{\frac{SD_{FC}^2 + SD_{TC}^2}{2}}$$

A positive value of d implies that the mean for the flipped class (FC; i.e., the experimental group) is greater than that for the traditional class (TC; i.e., the control group), whereas a negative value implies the opposite. After that, we sought explanations of the results (e.g., significant, non-significant, and group differences) through content analysis of the findings/results, discussions, and conclusions of the included studies (Creswell and Plano Clark, 2011; Akçayır and Akçayır, 2018).

RESULTS

Study Selection

By using the search string, a total of 1,186 peer-reviewed journal articles (published from January 2011 to December 2020) were found as of January 7, 2021 (the time of writing). However, 379 articles were removed due to duplication across databases. To recall, the aim of this review is to examine student engagement in mathematics flipped classrooms compared to their traditional counterparts. Although our search string provided the flexibility to capture a variety of terms used to refer to mathematics flipped classrooms, it also yielded many irrelevant search outcomes (e.g., research about Flipgrid and inverters). Therefore, after scanning their titles and abstracts, many articles were excluded because they were not relevant to the purpose of this review. Consistent with Bond (2020), we were aware that some researchers might evaluate some aspects of student engagement without explicitly mentioning them in their title or abstract. Therefore, the headings and subheadings of the articles were scanned in addition to their titles and abstracts.

Ultimately, 76 full-text articles were assessed for eligibility. These articles reported traditional-flipped comparisons in mathematics courses. However, more than half of them were excluded because they did not compare any aspects of student engagement under the two instructional environments. The final selection yielded 33 articles. There was perfect agreement of study selection between the two authors. It is worth noting that Lo and Hew (2020, 2021) reported their intervention in two different articles, and Zack et al. (2015), Hodgson et al. (2017), Rogers et al. (2017) reported more than one flipped course in their articles. Overall, a total of 39 unique individual flipped classroom interventions were involved in this review. **Figure 1** outlines the process of article selection.

Characteristics of the Included Studies

Twenty-four of the 33 included studies (72.7%) were published in the United States. Six studies were from the Asia-Pacific region, including Australia (Khan and Watson, 2018), China (Li et al., 2017; Wang et al., 2020), Hong Kong (Lo and Hew, 2020, 2021), and Taiwan (Bhagat et al., 2016). Three studies were from European countries, including Spain (López Belmonte et al., 2019), Sweden (Cronhjort et al., 2018), and the United Kingdom (Price and Walker, 2021). Except for the study of MBA students by Li et al. (2017), all studies were conducted at the undergraduate (n = 25) or secondary school (n = 7) level. In the 39 flipped classroom interventions, various content areas of mathematics were involved. At the undergraduate level, the three major content areas were statistics (n = 11), calculus (n = 9), and algebra (n = 4). At the secondary school level, most of the flipped courses (n = 5) introduced general mathematics. The background information and the major findings of the included studies are summarized in the **Table A1**.

To examine student engagement in mathematics courses, almost all included studies (n = 29) used student self-report surveys. Several researchers (e.g. Gundlach et al., 2015; Dove and Dove, 2017) adopted some established survey instruments,

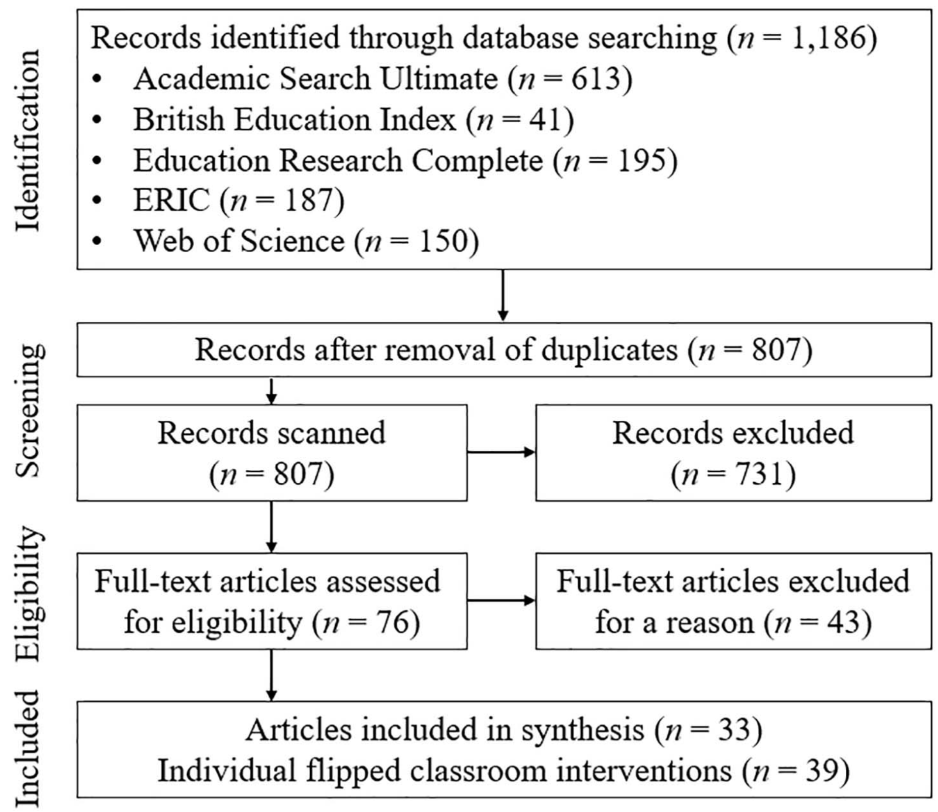

FIGURE 1 | Preferred reporting of items for systematic reviews and meta-analyses flow diagram of article selection.

such as the Survey of Attitudes Toward Statistics-36 (SATS-36; Vanhoof et al., 2011) and the Math Anxiety Rating Scale—Revised (MARS-R; Hopko, 2003). Other researchers developed their own surveys (e.g., Lo and Hew, 2021) or analyzed the results of their course evaluations (e.g., Peterson, 2016). In addition, some researchers conducted classroom observations (e.g., Hodgson et al., 2017), instructor interviews (e.g., Khan and Watson, 2018), and student interviews (e.g., Dove and Dove, 2017). Other methods employed in the included studies were attendance records (e.g., Heuett, 2017), individual quizzes (e.g., Nielsen et al., 2018), and optional assignments (e.g., Lo and Hew, 2020).

The results of our thematic analysis indicate that only about a quarter of the included studies (n = 8) covered all dimensions of student engagement (**Figure 2**). For example, Price and Walker (2021) compared students' attendance (i.e., behavioral engagement), level of interest (i.e., emotional engagement), and perceived course difficulty (i.e., cognitive engagement) in their flipped and traditional classes. Overall, we identified 114 comparison items that could be categorized under one of the three dimensions of student engagement. Forty items (35.1%) statistically supported the use of the flipped classroom approach, whereas 11 items (9.6%) were in favor of traditional lecturing. The difference between traditional and flipped classes in 49 items (43.0%) was found to be non-significant. For the remaining 14 items, the data reported in the included studies were not sufficient to determine the significance of the experimental effects statistically. **Figure 3** gives an overview of the results of our thematic analysis.

RQ1: Behavioral Engagement

Thirty-two out of 114 comparison items were related to students' behavioral engagement. Most of these items could be categorized under three major themes, including interaction (n = 13), attention/participation (n = 9), and effort (n = 7). A few items were concerned with student attendance (n = 2) under the two instructional environments. Finally, Lo and Hew (2021) examined students' overall behavioral engagement (n = 1) using the survey by Skinner et al. (2008). Their results suggested that the difference in student ratings between their traditional (n = 27, M = 4.15, SD = 0.45) and flipped (n = 28, M = 4.02, SD = 0.66) classes was not significant, p = 0.384. Overall, 12 of the 32 items (37.5%) statistically supported the use of the flipped classroom approach, 13 items (40.6%) were found to be non-significant, and one item (3.1%) was in favor of traditional lecturing. For the remaining six items, the data reported in the included studies were not sufficient to determine the significance of the experimental effects statistically.

First, **Table 1** shows that interaction in mathematics courses generally increased significantly after flipping, with effect sizes ranging from d = −0.10 to 1.39. For example, Wasserman et al. (2017) found that the use of the flipped classroom approach significantly promoted in-class communication in two

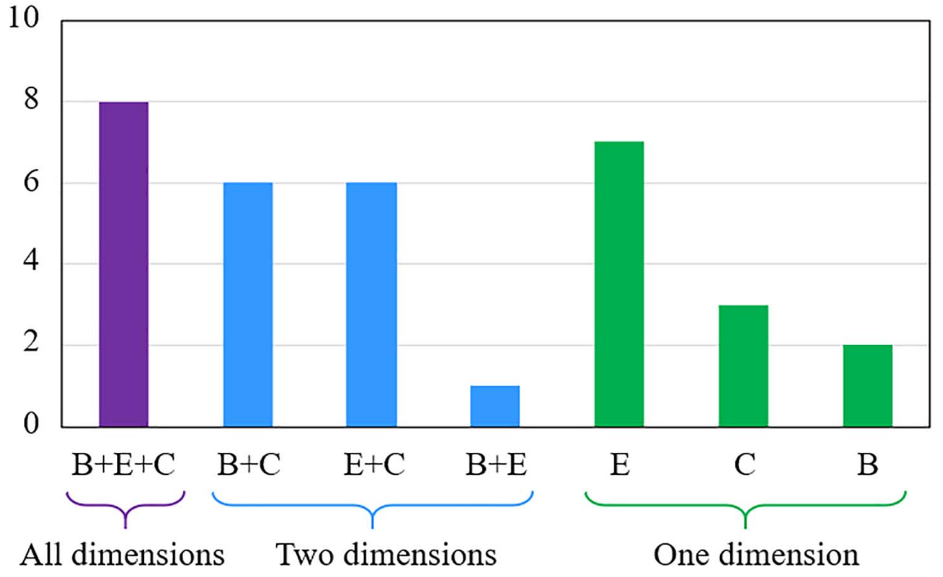

FIGURE 2 | Dimensions of student engagement covered in the included studies. B, Behavioral engagement; E, Emotional engagement; C, Cognitive engagement.

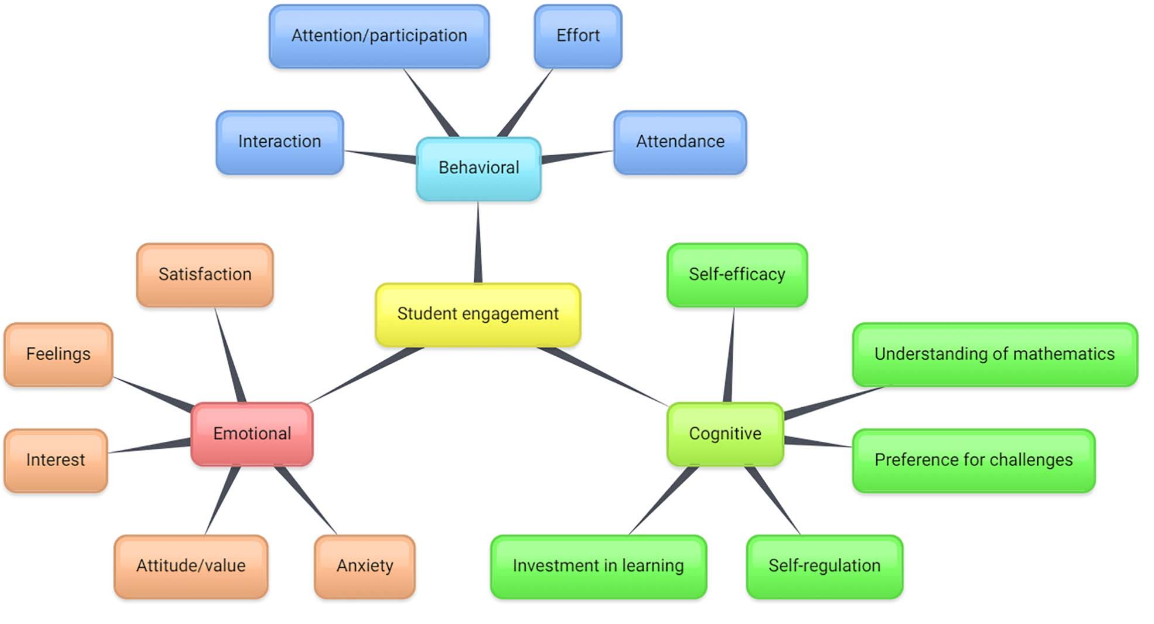

FIGURE 3 | The results of the thematic analysis of the comparison items.

consecutive semesters, with a large effect size. Besides the survey items in **Table 1**, Zack et al. (2015) reported the percentage of students who had a positive perception of instructor–student interaction during class. The differences between the traditional and flipped classes were within 20% in three of their courses, namely business calculus (TC = 91.3% vs. FC = 73.3%), calculus 1 (TC = 72.7% vs. FC = 60.0%), and finite math (TC = 60.0% vs. FC = 77.8%). In their precalculus course, however, only 16.7% of the students in the flipped class rated it positively, compared to 76.5% in the traditional class.

Second, **Table 2** shows that attention/participation in mathematics courses increased significantly in some courses after flipping, with effect sizes ranging from d = 0.39 to 0.92. Besides the survey items in **Table 2**, instructor interviews and classroom observations were conducted in some studies. The tutors in the study by Khan and Watson (2018) reported increased participation in the flipped classroom students' tutorials compared to those of the traditional classroom students. Through classroom observation, Rogers et al. (2017) analyzed students' percentage of time-on-task (e.g., taking notes and

TABLE 1 | Survey results: Interaction by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Wasserman et al., 2017	In-class communication (Fall, 2012)	TC = 37, FC = 33	7.53 (2.01)	**10.30 (1.98)**	**0.000**	**1.39**
Wasserman et al., 2017	In-class communication (Spring, 2013)	TC = 30, FC = 33	7.56 (2.04)	**9.46 (2.19)**	**0.001**	**0.90**
López Belmonte et al., 2019	Collaboration	TC = 30, FC = 30	2.30 (0.97)	**2.80 (0.87)**	**0.044**	**0.54**
Wasserman et al., 2017	Outside-of-class peer usefulness (Spring, 2013)	TC = 30, FC = 33	7.72 (2.55)	8.05 (2.21)	0.580	0.14
Cronhjort et al., 2018	Ability to get support from teachers, if needed	TC = 413, FC = 226	3.62	**4.22**	**0.000**	n/a
Cronhjort et al., 2018	Asking peers or teachers when didn't understand	TC = 413, FC = 226	4.16	**4.54**	**0.000**	n/a
Cronhjort et al., 2018	Learned by working together and discussing with others	TC = 413, FC = 226	4.08	**4.54**	**0.001**	n/a
Cronhjort et al., 2018	Talked about the course contents with peers outside the scheduled hours	TC = 413, FC = 226	4.13	**4.41**	**0.014**	n/a
Wasserman et al., 2017	Outside-of-class peer usefulness (Fall, 2012)	TC = 37, FC = 33	7.08 (2.62)	6.82 (2.68)	0.687	–0.10

Bold values indicate significant results.

TABLE 2 | Survey results: Attention/participation by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Bhagat et al., 2016	Attention	TC = 41, FC = 41	2.80 (0.77)	**3.55 (0.86)**	**<0.05**	**0.92**
López Belmonte et al., 2019	Participation	TC = 30, FC = 30	2.00 (0.89)	**2.83 (0.93)**	**0.001**	**0.91**
Amstelveen, 2019	The instructor created opportunities for me to participate in the classroom to support my learning in the course	TC = 20, FC = 29	2.85 (1.35)	3.41 (1.50)	0.188	0.39
Cronhjort et al., 2018	Active participation in the teaching	TC = 413, FC = 226	3.78	4.03	0.104	n/a

Bold values indicate significant results.

working). Their results suggested that students' time-on-task in the flipped class (92.4%) was slightly higher than that in the traditional class (84.1%). Hodgson et al. (2017) also observed student behavior during class. Among their three courses, the observers' ratings of student attention/participation under different instructional environments were statistically similar in their two algebra courses. Only in their general math course was the rating of their flipped class (*Mdn* = 4.66) significantly higher than that of their traditional class (*Mdn* = 3.50), $p = 0.011$.

Third, **Table 3** shows that except for Loux et al. (2016), student effort in the traditional and flipped classes was generally similar. For example, Nielsen et al. (2018) designed individual quizzes to measure student effort on the course. Their results suggested that the difference in scores between the traditional and flipped classes was not significant.

Finally, two studies compared student attendance under the two instructional environments. Heuett (2017) found that the number of days of absence per student in his flipped class ($M = 2.60$, $SD = 2.69$) was significantly higher than that in his traditional class ($M = 1.40$, $SD = 1.38$), $p = 0.012$. He suggested that this might be "a side-effect resulting from the direct instruction occurring via video outside of class" (p. 895). In contrast, Price and Walker (2021) examined the percentage of students attending seven or more tutorial sessions. Throughout the semester, they observed a downward trend in both the traditional and flipped classes without a significant difference (TC = 74.6% vs. FC = 71.7%), $p = 0.150$.

RQ2: Emotional Engagement

Forty-one out of 114 comparison items were related to students' emotional engagement. A majority of these items were categorized under three major themes, including course satisfaction ($n = 15$), feelings ($n = 10$), and interest ($n = 6$). The other items were concerned with students' attitudes toward and value placed on mathematics ($n = 5$) and anxiety ($n = 4$) under the two instructional environments. Finally, Lo and Hew (2021) examined students' overall emotional engagement ($n = 1$) using the survey by Skinner et al. (2008). Their results suggested that the difference in student ratings between the traditional ($n = 27$, $M = 4.16$, $SD = 0.48$) and flipped ($n = 28$, $M = 3.81$, $SD = 0.88$) classes was not significant, $p = 0.132$. Overall, 13 of the 41 items

TABLE 3 | Survey results: Effort by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Loux et al., 2016	Hours spent preparing for class	TC = 52, FC = 45	1.70 (1.42)	**2.50 (2.13)**	**0.016**	**0.44**
Loux et al., 2016	Hours spent completing homework	TC = 52, FC = 45	2.70 (1.80)	**3.30 (2.00)**	**0.046**	**0.32**
Nielsen et al., 2018	Average individual quiz score as a measure of effort	TC = 229, FC = 136	88.04 (7.30)	89.69 (5.65)	>0.05	0.25
Gundlach et al., 2015	Effort: Amount of work the student expends to learn statistics	TC = 193, FC = 25	6.01 (0.88)	6.11 (0.96)	>0.05	0.11
Cronhjort et al., 2018	Worked with the course contents regularly during the course	TC = 413, FC = 226	3.90	4.05	0.351	n/a
Peterson, 2016	Course was demanding	TC = 12, FC = 21	4.50 (0.67)	4.48 (0.68)	0.92	–0.03
Yong et al., 2015	Homework score as a measure of effort	TC = 90, FC = 86	92.43	90.78	>0.05	n/a

Bold values indicate significant results.

TABLE 4 | Survey results: Course satisfaction by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Wilson, 2013	Excellent course	TC = 2 classes of 20 to 25, FC = 2 classes of 20 to 25	3.85 (0.35)	4.40 (0.42)	n/a	1.42
Peterson, 2016	Overall quality of this course	TC = 12, FC = 21	4.00 (0.74)	**4.71 (0.46)**	**<0.01**	**1.15**
Bhagat et al., 2016	Satisfaction	TC = 41, FC = 41	2.96 (0.74)	**3.66 (0.74)**	**<0.05**	**0.95**
Peterson, 2016	Course was a significant contribution	TC = 12, FC = 21	3.83 (0.85)	**4.48 (0.88)**	**0.047**	**0.75**
Peterson, 2016	Course was well organized	TC = 12, FC = 21	4.67 (0.50)	4.81 (0.40)	0.37	0.31
Nielsen et al., 2018	Overall course rating	TC = 208, FC = 130	6.15 (1.25)	6.36 (1.14)	>0.05	0.18
Gundlach et al., 2015	Course rating	TC = 273, FC = 39	4.21 (0.75)	4.31 (0.69)	>0.05	0.14
Li et al., 2017	Course satisfaction score	TC = 45, FC = 75	91.69	**103.42**	**<0.001**	n/a
Touchton, 2015	Course mean	TC = 40, FC = 43	4.27	4.33	>0.05	n/a
Haughton and Kelly, 2015	Rating of course (Spring, 2013)	TC + FC = 231	2.93	3.17	0.08	n/a
Haughton and Kelly, 2015	Rating of course (Fall, 2013)	TC + FC = 250	2.73	2.81	0.98	n/a
Van Sickle, 2016	Overall, I rate the course as excellent	TC = 34, FC = 43	**4.34 (0.74)**	3.95 (1.06)	**0.04**	**–0.43**
DeSantis et al., 2015	Post-lesson feedback survey *[It appeared that the lower the value, the higher the satisfaction]*	TC = 21, FC = 26	**2.36 (0.50)**	2.72 (0.46)	**0.01**	**–0.75**

Bold values indicate significant results.

(31.7%) statistically supported the use of the flipped classroom approach, 16 items (39.0%) were found to be non-significant, and five items (12.2%) were in favor of traditional lecturing. For the remaining seven items, the data reported in the included studies were not sufficient to determine the significance of the experimental effects statistically.

First, **Table 4** shows that except for DeSantis et al. (2015) and Van Sickle (2016), the use of the flipped classroom approach can increase students' course satisfaction to a certain extent. The effect sizes ranged from $d = -0.75$ to 1.42. Several studies (i.e., Wilson, 2013; Bhagat et al., 2016; Peterson, 2016) even revealed a large effect size in favor of the flipped classroom approach. Besides the survey items in **Table 4**, Price and Walker (2021) found that 85.2% of their flipped classroom students rated the quality of their lectures as very good or excellent. This percentage was 20% higher than the lecture quality rating for their traditional class (65.1%). In contrast, the percentage of students who expressed satisfaction with the course was the same for traditional (about 73%) and flipped (about 73%) classes in the study by Ziegelmeier and Topaz (2015).

Second, the findings about students' feelings regarding the flipped classroom approach appear to be mixed across studies. Love et al. (2014) found that significantly more students felt comfortable talking with classmates in their flipped class (about 56%) compared to those in their traditional class (about 21%), $p = 0.003$. According to their pre- and post-survey on student enjoyment, Guerrero et al. (2015) found a positive change in the flipped class but a negative change in the traditional class. However, when comparing the percentage of students reporting a positive feeling about the classroom atmosphere, Zack et al. (2015) found that the effect of the flipped classroom approach was disappointing in some mathematics courses (precalculus: TC = 72.2% vs. FC = 5.6%; business calculus: TC = 73.9% vs. FC = 40.0%; calculus 1: TC = 81.8% vs. FC = 80.0%; finite math: TC = 50.0% vs. FC = 66.7%). **Table 5** further shows that the results of the survey items concerning feelings were

TABLE 5 | Survey results: Feelings by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Zack et al., 2015	The challenge of math appeals to me	TC = 64, FC = 49	2.98	2.57	0.074	n/a
Yong et al., 2015	In this course, I often felt excited about learning new concepts	TC = 90, FC = 86	3.64 (0.81)	3.54 (0.83)	0.624	–0.12
Gundlach et al., 2015	Affect: Students' feelings concerning statistics	TC = 193, FC = 25	4.92 (0.97)	4.55 (1.28)	>0.05	–0.33
Zack et al., 2015	When I hear the word math, I have a feeling of dislike *[i.e., a smaller value means a better effect]*	TC = 64, FC = 49	**2.62**	3.20	**0.039**	n/a

Bold values indicate significant results.

not in favor of the flipped classroom approach. For example, Zack et al. (2015) examined whether their students would have a dislike of mathematics at the end of their course. The rating for their flipped class was significantly higher (i.e., a higher level of dislike) than that for their traditional class, indicating an inferior effect after flipping.

Third, **Table 6** shows a mixed finding regarding student interest under different instructional environments. For example, Van Sickle (2016) found that the use of the flipped classroom approach impaired students' interest in her mathematics course, whereas Haughton and Kelly (2015) and Cronhjort et al. (2018) found the opposite. Besides the survey items in **Table 6**, Price and Walker (2021) compared the percentage of their traditional and flipped classroom students who found their course interesting. The results were statistically in favor of the flipped classroom approach (TC = 65.7% vs. FC = 84.2%), $p < 0.05$.

Finally, a few comparison items for emotional engagement in the included studies were categorized under attitude/value or anxiety. For attitude/value, the results of Li et al. (2017) suggested that their flipped classroom students ($n = 75$, $M = 60.97$, $SD = 5.33$) had a significantly more positive attitude toward cooperative mathematics learning compared to their traditional classroom students ($n = 45$, $M = 55.18$, $SD = 5.26$), with a large effect size of $d = 1.09$, $p = 0.01$. According to their pre- and post-survey on the value placed by students on mathematics, Guerrero et al. (2015) found a positive change in their flipped class but a negative change in their traditional class. However, the results of the studies by Gundlach et al. (2015), Kennedy et al. (2015), and Adams and Dove (2016) suggested that their traditional and flipped classes were statistically similar in terms of students' attitude/value. For anxiety, Dove and Dove (2017) found that the use of the flipped classroom approach could significantly reduce students' anxiety about mathematics (TC: $n = 32$, $M_{post-pre} = -6.50$, $SD = 1.70$ vs. FC: $n = 20$, $M_{post-pre} = -12.00$, $SD = 1.50$) and teaching mathematics (TC: $n = 20$, $M_{post-pre} = -6.00$, $SD = 2.30$ vs. FC: $n = 22$, $M_{post-pre} = -9.40$, $SD = 2.00$) in their mathematics content courses for pre-service teachers. In Dove and Dove (2015) and Kennedy et al. (2015), however, the difference in students' anxiety levels between their traditional and flipped classes appeared to be similar.

RQ3: Cognitive Engagement

Forty-one out of 114 comparison items were related to students' cognitive engagement. Most of these were categorized under three major themes, including self-efficacy ($n = 18$), understanding ($n = 12$), and preference for challenges ($n = 6$). The other items were concerned with students' self-regulation ($n = 2$) and investment in learning ($n = 2$). Finally, Lo and Hew (2021) examined students' overall cognitive engagement ($n = 1$) using the survey by Rotgans and Schmidt (2011). Their results suggested that the difference in student ratings between their traditional ($n = 27$, $M = 3.75$, $SD = 0.50$) and flipped ($n = 28$, $M = 3.58$, $SD = 0.70$) classes was not significant, $p = 0.304$. Overall, 15 of the 41 items (36.6%) statistically supported the use of the flipped classroom approach, 20 items (48.8%) were found to be non-significant, and five items (12.2%) were in favor of traditional lecturing. For the last item, the data reported in the included study were not sufficient to determine the significance of the experimental effects statistically.

First, **Table 7** shows a mixed finding about students' self-efficacy, with effect sizes ranging from $d = -0.62$ to 0.68. The studies by Touchton (2015), Bhagat et al. (2016), López Belmonte et al. (2019), provided evidence that the use of the flipped classroom approach significantly increased students' self-efficacy (i.e., confidence and self-perceived learning) compared to their counterparts in a traditional class, whereas Gundlach et al. (2015) found the opposite in terms of students' cognitive competence and the perceived easiness of statistics. The other studies shown in **Table 7** suggested that the differences between the two instructional environments were not significant. Besides the survey items in **Table 7**, Adams and Dove (2016) examined

TABLE 6 | Survey results: Interest by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Cronhjort et al., 2018	Encounter with the assignments that roused interest and engagement	TC = 413, FC = 226	3.47	**3.77**	**0.012**	n/a
Haughton and Kelly, 2015	Raised interest (Spring, 2013)	TC + FC = 231	2.68	**3.26**	**0.05**	n/a
Haughton and Kelly, 2015	Raised interest (Fall, 2013)	TC + FC = 250	2.65	2.63	0.25	n/a
Gundlach et al., 2015	Interest: Students' level of individual interest in statistics	TC = 193, FC = 25	4.64 (1.19)	4.48 (1.32)	>0.05	–0.13
Van Sickle, 2016	The instructor encouraged my interest in the course	TC = 34, FC = 42	**4.29 (0.71)**	3.79 (1.01)	**0.008**	**–0.57**

Bold values indicate significant results.

TABLE 7 | Survey results: Self-efficacy by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Bhagat et al., 2016	Confidence	TC = 41, FC = 41	3.16 (0.69)	**3.64 (0.72)**	**<0.05**	**0.68**
López Belmonte et al., 2019	Overall self-perceived learning	TC = 30, FC = 30	2.14 (0.91)	**2.76 (0.99)**	**0.021**	**0.65**
Wasserman et al., 2017	Resources acquired during course (Spring, 2013)	TC = 30, FC = 33	14.15 (2.98)	14.82 (2.58)	0.341	0.24
Touchton, 2015	Self-assessment of learning in the course	TC = 40, FC = 43	4.30	**4.51**	**<0.01**	n/a
Zack et al., 2015	I believe I am good at solving math problems	TC = 64, FC = 49	3.37	3.09	0.067	n/a
Kennedy et al., 2015	Self-efficacy	TC = 65, FC = 62	40.7 (9.67)	39.8 (9.45)	0.54	–0.09
Yong et al., 2015	I feel well-prepared for the next level of study in this field	TC = 90, FC = 86	3.89 (0.76)	3.82 (0.73)	0.570	–0.09
Wasserman et al., 2017	Resources acquired during course (Fall, 2012)	TC = 37, FC = 33	15.39 (2.46)	14.86 (3.37)	0.458	–0.18
Gundlach et al., 2015	Cognitive competence: Students' attitudes about their intellectual knowledge and skills when applied to statistics	TC = 193, FC = 25	**5.54 (0.90)**	5.05 (1.20)	**<0.05**	**–0.46**
Gundlach et al., 2015	Perceived easiness: Students' attitudes about the perceived easiness of statistics as a subject	TC = 193, FC = 25	**4.61 (0.82)**	4.07 (0.93)	**<0.05**	**–0.62**

Bold values indicate significant results.

the changes in students' efficacy, potential for mastery, and perception of difficulty of mathematics; Guerrero et al. (2015) and Loux et al. (2016) examined students' confidence in mathematics. The results of these studies indicated that the ratings of the traditional and flipped classroom students were statistically similar. In contrast, Heuett (2017) found that his flipped classroom students (about 85%) reported that they had significantly more confidence in their understanding of the course materials compared to his traditional classroom students (about 60%), $p = 0.030$.

Second, **Table 8** shows that except for Zack et al. (2015), the use of the flipped classroom approach can increase students' understanding of mathematics to a certain extent. The effect sizes ranged from $d = 0.37$ to 0.78. Besides the survey items in **Table 8**, Murphy et al. (2016) found that their flipped classroom students had a stronger belief that "the underlying mathematical ideas are more important than the formula" (p. 665) than their traditional classroom students. Meanwhile, they rated the proposition that "math is mostly a matter of memorizing formulas and procedures" (p. 665) significantly lower. As the researchers argued, these coupled questions provided evidence that their flipped classroom students finished the course with a better understanding of mathematics. Furthermore, Ziegelmeier and Topaz (2015) found that significantly more students in their flipped class (TC = about 68% vs. FC = about 89%) expressed the opinion that R (a statistical application) helped them to understand their course materials, $p = 0.028$. However, the results of other studies indicated that the students in the two instructional environments were statistically similar in terms of their self-consciousness about mathematics and the utility and importance of mathematics (Adams and Dove, 2016), as well as its perceived relevance to their future career (Love et al., 2014).

Third, there was evidence that the use of the flipped classroom approach can foster students' preference for challenges. Compared to their counterparts in a traditional class, the lecturer in the study by Khan and Watson (2018) reported that more students in their flipped class stayed after class to attempt challenging questions. In Lo and Hew (2020), nearly 70% of the students in the flipped class were willing to attempt an optional assignment and challenging questions, whereas fewer than 10% of the students in the traditional class submitted their assignment. Touchton (2015) found that the students in his flipped class (about 58%) were significantly more willing to take additional courses on his content area compared to those in his traditional class (about 26%), $p < 0.01$. **Table 9** further shows the results of the survey items about students'

TABLE 8 | Survey results: Understanding of mathematics by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Peterson, 2016	Clear explanations	TC = 12, FC = 21	4.33 (0.89)	**4.86 (0.36)**	**0.02**	**0.78**
Amstelveen, 2019	Supplementary material helped me learn the course material	TC = 20, FC = 29	2.94 (1.39)	**3.79 (1.37)**	**0.039**	**0.62**
Cronhjort et al., 2018	Related the course contents to real world examples	TC = 413, FC = 226	2.67	**2.94**	**0.048**	n/a
Amstelveen, 2019	Frequent feedback helped me improve my learning in the course	TC = 20, FC = 29	2.95 (1.35)	3.46 (1.4)	0.210	0.37
Cronhjort et al., 2018	The course felt relevant to my on-going studies	TC = 413, FC = 226	4.24	4.38	0.118	n/a
Zack et al., 2015	A strong math background can help me in my professional life	TC = 64, FC = 49	**3.62**	3.25	**0.029**	n/a
Zack et al., 2015	I believe that studying math helps me with problem solving in other areas	TC = 64, FC = 49	**3.57**	3.02	**0.002**	n/a

Bold values indicate significant results.

preference for challenges. In contrast to Touchton (2015) and Yong et al. (2015) found that the use of the flipped classroom approach did not affect students' preference for taking additional courses in their field.

Finally, a few comparison items for cognitive engagement in the included studies were categorized under self-regulation or investment in learning. For self-regulation, Kennedy et al. (2015) found that the students in their flipped class (n = 62, M = 243.40, SD = 33.07) rated significantly higher than the students in their traditional class (n = 65, M = 228.90, SD = 33.06) in terms of their learning strategies (e.g., rehearsal and elaboration), with a small effect size d = 0.44, p = 0.02. However, Wang et al. (2020) found that the difference between the traditional (n = 44, M = 33.25, SD = 5.33) and flipped (n = 44, M = 34.32, SD = 5.08) classes was not significant in terms of students' self-regulated learning, p = 0.71. For investment in learning, Cronhjort et al. (2018) used two survey items to examine the difference between their tradition and flipped classes: "Motivated to really learn to understand the course contents" and "When studying, tried to understand how things are connected" (p. 118). Students' ratings of the former item were significantly in favor of the flipped classroom approach (M_{TC} = 3.70 vs. M_{FC} = 4.16, $p < 0.001$), whereas the difference in the latter item was not significant (M_{TC} = 4.22 vs. M_{FC} = 4.28, p = 0.744).

DISCUSSION

This section discusses the results of our research synthesis and their implications for future practice and research.

Behavioral Engagement: Increased Interaction and Attention/Participation but Similar for Effort

We identified three major aspects of measuring behavioral engagement in the included studies, namely interaction, attention/participation, and effort. Most studies provided evidence that the use of the flipped classroom approach increased students' interaction and attention/participation compared to traditional lecturing. The classroom observation in Rogers et al. (2017) could advance our understanding of such an increase, as the researchers quantified the proportion of class time spent on different instructional activities under the two instructional environments. They found that the students in their traditional class spent most of their class time taking notes (42.6%) and listening (32.0%). In contrast, the students in their flipped class took notes while watching pre-class instructional videos in their individual learning space (Flipped Learning Network, 2014). More class time could thus be spent working on mathematical tasks (35.1%). Most importantly, the percentage of time spent on peer-to-peer collaboration increased from 1.3 to 15.5% after flipping. As echoed by other studies (e.g., Wasserman et al., 2017; Cronhjort et al., 2018; Khan and Watson, 2018), these problem-solving activities not only facilitated instructor–student and student–student interaction but also better supported their attention and participation in the classroom.

Notwithstanding the increase in interaction and attention/participation, students' levels of effort appeared to be similar in traditional and flipped classrooms across studies. However, we are cautiously positive regarding this non-significant result. As Peterson (2016) commented, "the students in the flipped section did not find the course to be any more demanding than the lecture (traditional) section" (p. 13). Due to the amount of work required, some flipped classroom interventions overwhelmed and frustrated students (Lo et al., 2017; van Alten et al., 2019; Bond, 2020). In the words of one student, "I felt as if I didn't have enough time to finish what I needed, so I felt rushed. For this reason, I didn't really enjoy the flip" (Moran, 2018, p. 11). Therefore, instructors should maintain a similar course workload when transforming their traditional lecture-based mathematics course into a flipped one. As Wasserman et al. (2017) specified, the total time required for students to complete out-of-class work for flipped classrooms (e.g., class preparation) should be approximately the same as for traditional classrooms (e.g., homework).

Emotional Engagement: Increased Satisfaction but Mixed Results for Feelings and Interest

We identified three major aspects of measuring emotional engagement in the included studies, namely course satisfaction, feelings, and interest. Most studies supported the idea that the use of the flipped classroom approach increases students' course satisfaction compared to traditional lecturing. This result is not consistent with the review by van Alten et al. (2019). The researchers conducted a meta-analysis of 22 studies across contexts and subject disciplines and found that the overall effect size of the flipped classroom approach was negligible and non-significant (Hedges' g = 0.05, 95% CI = [−0.23, 0.32], p = 0.73). In particular, more than half of their included studies reported a negative or neutral effect, whereas this review found the opposite in mathematics education. For example, Wilson (2013), Bhagat et al. (2016), and Peterson (2016), found that students' rating of course satisfaction in their flipped class was

TABLE 9 | Survey results: Preference for challenges by effect size.

Study	Survey items	$n_{observation}$	TC *M* (*SD*)	FC *M* (*SD*)	*p*	*d*
Cronhjort et al., 2018	The course was challenging in a positive way	TC = 413, FC = 226	3.90	**4.32**	**0.000**	n/a
Cronhjort et al., 2018	During the course, worked hard to learn what was difficult	TC = 413, FC = 226	3.75	3.91	0.269	n/a
Yong et al., 2015	I look forward to taking more courses in this field	TC = 90, FC = 86	3.64 (1.00)	3.66 (0.83)	0.895	0.02

Bold values indicate significant results.

significantly higher than that in their traditional class, with a large effect size. Bhagat et al. (2016) explained that their flipped classroom students could access their pre-class learning materials at a time convenient to them, which was not possible for those in their traditional classroom. Inside the classroom, their students, especially those who were underperforming, could receive more support from their instructor and peers because the class time was no longer occupied by direct instruction. As Peterson (2016) concluded, the instructional sequence of the flipped classroom approach caused the difference indicated in course satisfaction.

Despite the increased course satisfaction, the results regarding students' feelings and interests were mixed. The studies by Zack et al. (2015) and Van Sickle (2016) even provided evidence that the use of the flipped classroom approach could have a negative impact on these two aspects. Van Sickle (2016) explained that the students in her flipped class often had a hard time during class meetings because the in-class work problems were difficult. This negative experience thus impaired their emotional engagement. In their reflection, Zack et al. (2015) suggested designing a wide variety of in-class activities to ensure student engagement during class. Similarly, Cronhjort et al. (2018) emphasized the value of using a broad range of learning activities in their flipped classroom. At the start of lessons, they would first ensure that students had adequate preparation for handling more advanced learning tasks by offering instructor-led reviews. After that, they used multiple-choice questions (easy), hands-on exercises (medium), and applied problems (hard) to guide student learning. As a result, their flipped classroom students had a higher level of interest in the learning tasks compared to their traditional classroom students. In future practice, instructors should design a sequence of in-class learning activities for students to develop the desired mathematical knowledge and skills progressively.

Cognitive Engagement: Mixed Results for Self-Efficacy but Increased Understanding of Mathematics and Preference for Challenges

We identified three major aspects of measuring cognitive engagement in the included studies, namely self-efficacy, understanding of mathematics, and preference for challenges. The results regarding students' self-efficacy were mixed across studies. We found that the use of the flipped classroom approach in Gundlach et al. (2015) produced the least favorable effect. One possible reason for such a decrease might be the reduction of class time after flipping. The students in the traditional class would meet their instructor or teaching assistant three times a week (a total of 150 mins) but only once a week (a total of 75 mins) in the flipped class. Gundlach et al. (2015) thus lamented that the instructor's formative feedback opportunities were sacrificed. In contrast, Touchton (2015) was able to provide students with immediate feedback during class. He argued that the feedback could prevent students from acquiring bad habits in solving statistical problems. As a result, the students in his flipped class had greater confidence in applying their knowledge compared to those in his traditional class. From the perspective of self-determination theory, timely feedback is essential to increase students' self-efficacy and thus their cognitive engagement (Fredricks et al., 2004; Niemiec and Ryan, 2009).

Despite the mixed results regarding self-efficacy, most studies provided evidence that the use of the flipped classroom approach increased students' understanding of mathematics and fostered their preference for challenges. We found that the interventions with a positive effect (e.g., Touchton, 2015; Ziegelmeier and Topaz, 2015; Murphy et al., 2016; Cronhjort et al., 2018; Lo and Hew, 2020) generally emphasized the real-world applications of course materials. For example, Lo and Hew (2020) used their class time better after flipping by engaging students in solving real-world problems. In an optional learning task in their course, most students in their flipped class were willing to attempt challenging questions, whereas those in their traditional class were not. Touchton (2015) designed his learning tasks using authentic examples, such as the statistical models presented in journal articles. With more class time devoted to applying what they had learned in their course, his flipped classroom students were better able to master and understand the value of the course materials. Therefore, they had a greater willingness to pursue additional training compared to his traditional classroom students.

To summarize, the results of our research synthesis have the following implications for future flipped classroom practice to support student engagement. These implications are related to the design features (i.e., retaining student workload and facilitating collaborative problem-solving) and elements (i.e., the use of in-class review, real-world problems, and instructor feedback) of mathematics flipped classrooms.

(1) Student workload: Retaining the same level of course workload when transforming a traditional lecture-based course into a flipped one.
(2) In-class review: Offering instructor-led reviews at the start of lessons to ensure students' readiness to handle advanced problems.
(3) Collaborative problem-solving: Engaging students in solving a progression of problems with peer support.
(4) Real-world problems: Enabling students to appreciate the usefulness of course materials by using real-world mathematical problems.
(5) Instructor feedback: Using class time to provide feedback on student performance and clarify their misunderstandings.

Limitations and Implications for Future Research

Although this review can contribute to our understanding of student engagement in mathematics flipped classrooms, several limitations must be acknowledged. These limitations have important implications for future research regarding the research contexts, focuses, and methods. First, the majority of the comparative studies of student engagement were conducted in the United States and in higher education contexts. Therefore, the results of this review may not be generalizable to other contexts. Further research is required to examine the effect of the flipped classroom approach on non-United States (e.g., Asian) and/or K–12 students' engagement in mathematics courses.

Second, this review discovered quite a few aspects of student engagement that have not been thoroughly explored. For behavioral engagement, only two included studies (i.e., Heuett, 2017; Price and Walker, 2021) compared students' attendance in their traditional and flipped classes. For emotional engagement, only three included studies (i.e., Dove and Dove, 2015, 2017; Kennedy et al., 2015) focused on mathematics anxiety. In particular, the usefulness of the findings of Dove and Dove (2015, 2017) may be confined to mathematics courses for pre-service teachers. For cognitive engagement, only two included studies (i.e., Kennedy et al., 2015; Wang et al., 2020) examined students' self-regulation in their flipped classes compared to their traditional classes. Due to the limited number of studies, conclusions cannot be drawn about students' attendance, mathematics anxiety, self-regulation, or other minor themes (e.g., attitude/value and investment in learning). Future research could focus on these aspects and evaluate the effect of the flipped classroom approach.

Third, most of the included studies used self-report surveys to evaluate student engagement with their mathematics courses. However, the survey items were diverse across studies. As noted previously by Bond (2020), such a diversity of measurements hinders further quantitative analysis (e.g., meta-analysis) of student engagement. Therefore, we suggest using some established survey instruments (e.g., Gundlach et al., 2015; Dove and Dove, 2017) or developing the instruments based on the literature on student engagement (e.g., Lo and Hew, 2021) in future research, which will enable a better comparison and synthesis across studies. Besides, the results of this review were largely based on the self-report survey data of the included studies. However, the results of these self-report data should be viewed with caution because the research participants may have provided socially desirable responses. Therefore, more objective measurements of student engagement should be used in future research, such as classroom observation (to monitor students' behavior) and optional assignments (to evaluate students' preference for challenges).

CONCLUSION

This review focused on student engagement in mathematics courses under different instructional approaches. Thirty-three traditional-flipped comparative studies were analyzed. The results suggested that the use of the flipped classroom approach could increase certain aspects of behavioral engagement (i.e., interaction and attention/participation), emotional engagement (i.e., satisfaction), and cognitive engagement (i.e., understanding of mathematics and preference for challenges). However, the results with respect to a few aspects of emotional engagement (i.e., feelings and interest) and cognitive engagement (i.e., self-efficacy) appeared to be mixed across studies. Based on the results of our research synthesis, several recommendations for future practice and research were made. This review thus contributed to our understanding of (1) the effect of using the flipped classroom approach on student engagement in mathematics education, (2) how to better support student engagement in future flipped classroom practice, and (3) possible directions for further research on flipped classrooms.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

CL performed the analysis and wrote the first draft. KH helped to revise the manuscript. Both authors contributed to the design of the study, data collection, data coding, and read and approved the final manuscript.

FUNDING

This research was supported by a grant from The Education University of Hong Kong, Project Reference Number: RG 64/2019-2020R.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX

TABLE A1 | This appendix provides a summary of the background information and the major findings of the included studies.

Study	Location	Subject area (Grade level)	Major findings
Adams and Dove, 2016	United States	Calculus (UG)	The flipped classroom approach was not found to have any significant impact on students compared to traditional lecturing. However, the flipped classroom students showed appreciation for this new instructional approach and wished to take more mathematics courses using it.
Amstelveen, 2019	United States	Algebra (UG)	There were no significant differences on in-class exams between the traditional and flipped classes. However, the students in the flipped class perceived that the video lectures helped them to learn more mathematics compared to those in the traditional class.
Bhagat et al., 2016	Taiwan	Trigonometry (SS)	The flipped classroom students had significantly higher learning achievement and motivation than the traditional classroom students. The performance of low achievers in the flipped class was better than those in the traditional class.
Cronhjort et al., 2018	Sweden	Calculus (UG)	Compared to the traditional class, the normalized learning gain was 13% higher in the flipped class. Besides, the flipped classroom students rated significantly higher on their engagement survey.
DeSantis et al., 2015	United States	Geometry (SS)	There were no significant differences in the learning outcomes between the traditional and flipped classes. However, the students in the traditional class reported significantly higher satisfaction with their own learning than those in the flipped class.
Dove and Dove, 2015	United States	Math content course for pre-service teachers (UG)	The mathematics anxiety scores decreased significantly in both the traditional and flipped classes. However, the flipped classroom students achieved significantly higher in the overall course grades.
Dove and Dove, 2017	United States	Math content course for pre-service teachers (UG)	Students' anxieties related to mathematics were improved in both the traditional and flipped classes. In the flipped class, teacher-created videos better aligned with course content and activities. Therefore, the students felt prepared and more confident before entering the classroom.
Guerrero et al., 2015	United States	Finite math (UG)	The use of the flipped classroom approach had positive effects on student attitudes toward mathematics. However, the new instructional approach had no significant impact on student learning over traditional lecturing.
Gundlach et al., 2015	United States	Statistics literacy (UG)	The traditional classroom students scored higher on average on all three exams compared to the flipped classroom students. However, their differences in homework, projects, and university evaluations of the course and instructor were not significant.
Haughton and Kelly, 2015	United States	Statistics (UG)	The flipped classroom students performed better than the traditional classroom students on the common final exam. However, there were no significant differences in the final grades and student satisfaction between the traditional and flipped classes.
Heuett, 2017	United States	Statistics (UG)	The flipped classroom students performed better than the traditional classroom students on exams. Moreover, they were more confident about their abilities and their understanding of the course materials.
Hodgson et al., 2017	United States	Algebra (SS); Algebra (SS); General math (SS)	An increase in engagement was found in only one of the three flipped classes. Student engagement was affected by student characteristics and instructors' skills and expectations.
Kennedy et al., 2015	United States	Calculus (UG)	The students in the traditional class significantly outperformed those in the flipped class on conceptual portions of some exams. Moreover, the overall motivation score for the flipped classroom students significantly dropped from the pre-test to the post-test. Nevertheless, there was an increase in both the rehearsal score and peer learning score for the flipped classroom students.
Khan and Watson, 2018	Australia	Statistics (UG)	The use of the flipped classroom approach improved student performance, understanding of concepts, and student engagement. The findings of student feedback indicated a higher preference for the flipped classroom approach, especially for ages 20 and below.
Li et al., 2017	China	Statistics (MBA)	There were no significant differences in learning achievement, course satisfaction, and cooperative learning attitudes between the traditional and flipped classes. Web-based learning self-efficacy influenced their learning achievement and course satisfaction.

(Continued)

TABLE A1 | Continued

Study	Location	Subject area (Grade level)	Major findings
Lo and Hew, 2020, 2021	Hong Kong	General math (SS)	Compared to traditional lecturing, the use of the flipped classroom approach with gamification improved students' learning achievement and their submission rate of an optional assignment (i.e., their preference for challenges). However, the survey results indicated that students' behavioral, emotional, and cognitive engagement were similar under different instructional environments.
López Belmonte et al., 2019	Spain	General math (SS)	The use of the flipped classroom approach improved several attitudinal (including motivation, autonomy, collaboration, and participation) and mathematical (including scientific data, graphics, results, and decision) dimensions compared to traditional lecturing.
Loux et al., 2016	United States	Statistics (UG)	The flipped classroom students reported very high satisfaction with the instructional approach. However, students' end-of-semester opinions and levels of confidence were similar in the traditional and flipped classes.
Love et al., 2014	United States	Algebra (UG)	The students in the flipped class experienced a more significant increase between the sequential exams compared to those in the traditional class. However, they performed similarly in the final exam. The flipped classroom students were very positive about their experience in the course and appreciated the student collaboration and instructional video components.
Murphy et al., 2016	United States	Algebra (UG)	The flipped classroom students performed better in the overall comprehension of content with a 21% increase in the median final exam score. They felt more confident in their ability to learn mathematics independently, showed better retention of materials over time, and enjoyed the experience in the flipped classroom.
Nielsen et al., 2018	United States	Statistics (UG)	The use of the flipped classroom approach significantly improved student performance and course satisfaction. With the help of teaching assistants and the use of additional classrooms, the instructional approach could be used in large lecture classes.
Peterson, 2016	United States	Statistics (UG)	The students in the flipped class outperformed those in the traditional class by more than a letter grade on the final exam. The flipped classroom students were more satisfied with the course overall. These results were likely due to the strong cohesion between the in-class and out-of-class content.
Price and Walker, 2021	United Kingdom	Statistics (UG)	There were no significant differences in exam performance, class attendance, and online engagement between the traditional and flipped classes. Student perceptions of the flipped classroom approach differed according to gender, nationality, and reported prior mathematics training.
Rogers et al., 2017	United States	Algebra (SS); Pre-AP (SS); General math (SS)	Student engagement in the flipped classes was higher than that in the traditional classes. The flipped classroom students spent more class time working on mathematics topics and collaborating with peers, whereas the traditional classroom students spent more time taking notes.
Touchton, 2015	United States	Statistics (UG)	The flipped classroom approach gave students a statistically significant advantage in difficult and applied areas emphasized in class. The students in the flipped class expressed that they learned more and enjoyed the course more than those in the traditional class.
Van Sickle, 2016	United States	Algebra (UG)	The flipped classroom students scored higher than the traditional classroom students in the final exam. However, their perception of several measures decreased significantly, including how interested they were in the course and whether the instructor effectively facilitated learning.
Wasserman et al., 2017	United States	Calculus (UG)	Student performance on procedural problems was similar in the traditional and flipped classes. The flipped classroom students reported increased communication during class, but the traditional classroom students perceived more effective use of class time.
Wilson, 2013	United States	Statistics (UG)	The use of the flipped classroom approach freed up more class time for interactive activities. It had a positive impact on students' attitudes toward the class and instructor as well as on their performance.
Yong et al., 2015	United States	Calculus (UG)	The differences in learning, metacognitive, and affective gains between the traditional and flipped classes were not significant. These results were likely due to contextual factors (e.g., a strong group-work culture) in the research site.
Zack et al., 2015	United States	Finite math (UG); calculus (UG); calculus (UG); calculus (UG)	No statistical difference was found in the test scores of the traditional and flipped classroom students. However, many flipped classroom students had negative opinions of the new instructional approach and their attitudes toward mathematics tended to decline in general.
Ziegelmeier and Topaz, 2015	United States	Calculus (UG)	The traditional and flipped classroom students scored similarly on the graded components of the course. Moreover, the majority of students in both classes were comfortable with the course format.

SS, Secondary school; UG, Undergraduate.

frontiers in Psychology

ORIGINAL RESEARCH
published: 17 June 2021
doi: 10.3389/fpsyg.2021.663202

Comparison Between Performance Levels for Mathematical Competence: Results for the Sex Variable

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Schools promote all-round education for each of their students. This requires teachers to work on all of the possibilities offered by a subject, including mathematical ability. This process of adjustment and individualization is essential for students who have excellent performance or aptitudes. This study uses an *ex post* facto, descriptive and quantitative research methodology to examine the results of giving the online version of the Evaluation Battery for Mathematical Ability (BECOMA On) to 3795 5th-year primary school students. The sample was selected from 147 Spanish schools from 16 autonomous regions and 2 autonomous municipalities. Three levels of performance were identified, 3 being the highest, and different statistical indices were calculated for each of them. The results were also analyzed according to sex, with statistically significant differences in the highest performance level. In addition, the study highlighted a diagnostic gap in the identification of higher capacity students, a pending challenge for education systems for the educational inclusion of all students.

Keywords: math performance, assessment instrument, primary education, educational inclusion, sex

OPEN ACCESS

Edited by:
Jin Su Jeong,
University of Extremadura, Spain

Reviewed by:
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University of Beira Interior, Portugal
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *02 February 2021*
Accepted: *19 May 2021*
Published: *17 June 2021*

Citation:
García Perales R and Palomares Ruiz A (2021) Comparison Between Performance Levels for Mathematical Competence: Results for the Sex Variable. Front. Psychol. 12:663202. doi: 10.3389/fpsyg.2021.663202

INTRODUCTION

Educational processes nowadays are characterized by homogeneity and multidimensionality, which makes it difficult to deal with the diverse potentials, needs, and interests in the classroom. Occasionally, there may also be a lack of diagnostics that would allow for the modified, individualized educational responses which are common for students who are highly capable and have high aptitudes (García-Perales and Almeida, 2019). Discovering and working on talent should be a basic objective in an advanced society, and generalizing the detection process and targeting it at the entire school population would be an interesting way of achieving that aim. This study presents an example of that in the field of mathematics. The process allows various situations to be addressed flexibly based on specific student characteristics in order to encourage each student's cognitive abilities to the highest level.

Mathematics is important because it is applicable in daily life and in solving various types of problems (Cázares et al., 2020), as well as having interdisciplinary connections to other parts of the curriculum (Gilat and Amit, 2013). This generalization to routine everyday contexts is a fundamental aspect of being included as a key skill in education (Méndez et al., 2015). In the case of mathematics, it is included in maths competency and basic competencies in science and technology. Maths competency is defined as "students' ability to formulate, apply, and interpret mathematics in various contexts. It includes mathematical reasoning and using mathematical concepts, procedures, facts, and tools to describe, explain, and predict various kinds of phenomena" (Ministerio de Educación y Formación Profesional, 2019, p. 17). This definition provides a key aspect of maths evaluation, the measurement of mathematical ability in a broad range of contexts, with a view to highlighting the importance of generalizing what has been learned to a wide variety of situations, familiar or otherwise. The search for constructive, committed, reflective citizenship is a fundamental premise of educational processes, aspects which maths teaching has a strong influence over (Organization for Economic Cooperation, and Development, 2019b). Maths competence has been evaluated in all six editions of the Program for International Student Assessment (PISA) every three years from 2000 to 2018.

The PISA assessments are a fundamental reference for evaluation. The fact that there is a large, worldwide sample for the PISA tests means that the conclusions are extremely important in the development of education policy. Its conceptual framework has been used in many studies (García-Perales, 2014; Ferreira et al., 2017; Rodríguez-Mantilla et al., 2018; Fuentes and Renobell, 2019; Sason et al., 2020). The distinctive characteristics of PISA include (Ministerio de Educación y Formación Profesional, 2019): seeking to guide educational policies, integration of the concept of competence in assessment, the important role of autonomous and lifelong learning, regular deployment, and sensitive international coverage. When interpreting results for each item, PISA uses Item Response Theory (IRT). In this regard, children's answers are considered according to the child's level of ability in mathematical competence, in other words, estimates of student performance focus on the type of mathematical tasks that they can solve correctly (Ministerio de Educación y Formación Profesional, 2019). This means performance levels can be identified that allow each child to be placed on a continuous scale of competence for the measured construct (Roderer and Roebers, 2013), showing the percentage of subjects in each level together with their distinctive characteristics, in this case for mathematical competence. This methodology was used with the BECOMA On, the instrument in the present study, in which three performance levels were set based on the scores.

Among the many conclusions from PISA relating to mathematics, reports have stressed that students' interest in and enjoyment of this area is low, and even noted the presence of personal issues such as anxiety and lack of confidence, especially in girls (Organization for Economic Cooperation, and Development, 2013; Mizala et al., 2015; Organization for Economic Cooperation and Development, 2019d). Throughout the PISA assessments, boys have always had better results than girls in mathematical competence (Ministerio de Educación y Formación Profesional, 2019), with sex being a predictor variable of mathematical performance (Farfán and Simón, 2017; Fuentes and Renobell, 2019; Palomares-Ruiz and García-Perales, 2020). Biological and social factors may act in an interrelated way (Chamorro-Premuzic et al., 2009; Muelas, 2014), including intellectual capacity (Schillinger et al., 2018), complex mathematical reasoning (Desco et al., 2011) and other factors of an individual nature with an impact on the mathematical learning process (Song et al., 2010; Marsh and Martin, 2011; Rodríguez and Guzmán, 2018), school (Carey et al., 2016; Dowker et al., 2016; Schillinger et al., 2018), and family (Pelegrina et al., 2002; Ferreira et al., 2017; Rodríguez-Mantilla et al., 2018). Analyzing students' mathematical performance according to sex is one objective of the present study.

The results for mathematics performance in the 2012 PISA tests—the most recent that evaluated mathematics preferentially—and the 2018 tests—the most recent evaluation—are summarized briefly below. In PISA, student results are ranked in seven performance levels: below level 1, 1, 2, 3, 4, 5, and 6. In PISA 2012, Spanish boys scored an average of 492 points and Spanish girls averaged 476 points (Ministerio de Educación, Cultura y Deporte, 2014a). In PISA 2018, Spanish boys averaged 485, while the girls averaged 478. In both cases, the differences between sexes were statistically significant (Ministerio de Educación y Formación Profesional, 2019). Examining these differences more closely, the results for the highest levels 5 and 6 stand out; in PISA 2018, 8% of boys and 5.50% of girls were in one of these two levels. Other studies have also indicated these differences between the sexes in performance and higher ability (Llor et al., 2012; García-Perales and Almeida, 2019; Ministerio de Educación y Formación Profesional, 2020; Palomares-Ruiz and García-Perales, 2020). In contrast, 24.60% of boys and 24.80% of girls were in the lowest levels—1 and below 1—with no statistical significance between the sexes (Ministerio de Educación y Formación Profesional, 2019). As **Figure 1** shows, at the higher performance levels the differences between the sexes begin to be more significant, with more boys than girls in those higher levels of mathematics performance (something which is also seen in the OECD average). This is an issue that raises concerns about the potential consequences for future academic and professional choices.

Continuing to look at children with excellent performance in mathematics, in PISA 2012, 8% of Spanish students exhibited excellent performance (6.70% and 1.30% in the two top performing groups), similar figures to previous editions of PISA for mathematics skills, whereas the OECD average was 9.30% and 3.30% in the top two groups (Instituto Nacional de Evaluación Educativa, 2013). In PISA 2018, 6% and 1% of Spanish students were in the top two groups, whereas the OECD mean was 9% and 2% respectively (Ministerio de Educación y Formación Profesional, 2019; Organization for Economic Cooperation, and Development, 2019a,b,c). This raises a fundamental question. In Spain do we not have high performing students? or is our own system not capable of identifying and cultivating them?

What makes a student highly capable at mathematics? PISA 2018, the most recent version, set out the following characteristics for achievement level 6 or higher for maths skills (Ministerio de Educación y Formación Profesional, 2019, p. 64):

"They know how to formulate concepts, generalize and use information based on their research and model complex problems, and they can use their knowledge in relatively atypical contexts. They can simultaneously relate different sources of information and representations, and switch between them flexibly. Students at this level have a high level of

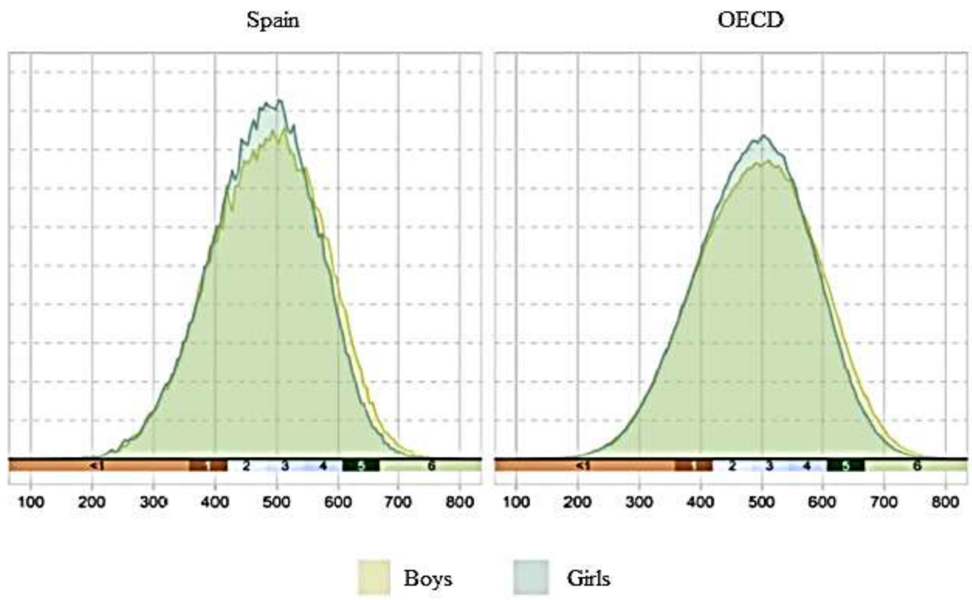

FIGURE 1 | Performance levels and gender in PISA 2018 for Spain and the OECD. Source: Ministerio de Educación y Formación Profesional (2019), p. 89.

mathematical thinking and reasoning. These students can apply this comprehension, as well as their mastery of mathematical operations and symbolic, formal relationships to develop new approaches and strategies to address new situations. Students at this level can consider their actions, and precisely formulate and communicate their actions and thinking about their discoveries, interpretations, arguments, and adaptation to novel situations."

Other research also influences the conceptualization of the most mathematically capable children (Geary and Brown, 1991; Greenes, 1997; Sriraman, 2003; Rotigel and Fello, 2004; Almeida et al., 2008; Desco et al., 2011; Jaime and Gutiérrez, 2017; Kurnaz, 2018; Ramírez and Cañadas, 2018). Within the field of higher abilities, it is worth paying particular attention to the female population. For example, in Spain, the percentages diagnosed as highly able in school year 2018/19 varied considerably by sex, 65.06% of those identified were boys and 34.94% were girls (Ministerio de Educación y Formación Profesional, 2020). Girls are a higher risk group among the highly able, the identification processes are more detrimental to them (Kerr, 2000; Landau, 2003; Jiménez, 2014) and stereotypes abound (Bian et al., 2017). In addition, even nowadays there are still inequalities in the socialization processes between the sexes (Hadjar et al., 2014; Ministerio de Educación y Formación Profesional, 2019), and girls' potentials are occasionally undervalued (Pomar et al., 2009). UNESCO (2019, p.72) stated that "the disadvantaging of girls is not based on cognitive ability, but rather on the processes of socialization and learning they grow up with, which shape their identities, beliefs, behaviors, and life choices."

There is research into maths competency indicating that boys tend to get better results (Preckel et al., 2008; Llor et al., 2012;

TABLE 1 | Performance levels in BECOMA On.

Level	Intervals	*n*	%	Valid%	Cumulative%
1	<=30	1319	34.75	34.75	34.75
2	31 – 39	1263	33.28	33.28	68.03
3	40 – 60	1213	31.96	31.96	100.0
	Total	3795	100.0	100.0	

Source: Authors' own work.

TABLE 2 | Instrument structure.

Dimension	Evaluation test	Items	Percentage	Total percentage
Statistics and Probability	1st Mathematical interpretation	1, 2, 3, 4, 5	16.67	16.67
Arithmetic	2nd Mental arithmetic	6, 7, 8, 9, 10, 11	20	46.67
	4th Logical numerical series	14, 15, 16, 17, 18, 19,	20	
	5th Discovering algorithms	20, 21	6.67	
Geometry	3rd Geometrical properties	12, 13	6.67	16.67
	7th Logical series of figures	28, 29, 30	10	
Magnitudes and Proportionality	6th Conventional units	22, 23, 24, 25, 26, 27	20	20
Total	7	30	100	100

Source: Authors' own work.

Instituto Nacional de Evaluación Educativa, 2013; Ministerio de Educación y Formación Profesional, 2019) despite both sexes receiving similar mathematics teaching from the beginning of schooling. Perceptions of and attitudes toward mathematics are particularly important (González-Pienda et al., 2012; Mato et al., 2014; Ministerio de Educación, Cultura y Deporte, 2014b; Preckel et al., 2008; Ministerio de Educación y Formación Profesional, 2019; Cueli et al., 2020; Palomares-Ruiz and García-Perales, 2020), girls can exhibit anxiety and lack confidence in this area (Instituto Nacional de Evaluación Educativa, 2013; Rodríguez-Mantilla et al., 2018). It is essential to consider girls' levels of attention or execution rates in approaching mathematical tasks (Boaler, 2016; Farfán and Simón, 2017; Hattie et al., 2017; Rodríguez and Guzmán, 2018; Cueli et al., 2020), as well as other motivational and emotional factors (Else-Quest et al., 2010; Rodríguez-Mantilla et al., 2018). Teacher training and practice must consider these discrepancies between aptitude and attitude toward mathematics (Nortes and Nortes, 2013; Rico et al., 2014; Ursini and Ramírez-Mercado, 2017). This variable is a key determiner of educational success in any academic discipline. The more interested students are and the more they believe learning mathematics to be a useful source of knowledge, the better their performance will be (Figueiredo and Guimarães, 2019). This becomes even more important when changing educational stages in the face of deteriorating attitudes toward learning (Mato et al., 2014). Self-efficacy also influences educational development and is a key variable to consider in students' individual adjustment in the area of mathematics (Ruiz, 2005; Zalazar et al., 2011; Rosário et al., 2012). Better and deeper understanding of these attitudinal and motivational aspects is an essential challenge for mathematics teaching.

Understanding the dimensions that can have an impact on men's and women's educational paths is key and affects future academic and professional choices (Hadjar et al., 2014; UNESCO, 2019; García-Perales et al., 2021). It is essential to try to extrapolate from research to answer the question; why is there a difference in the choice of scientific and technical careers between

TABLE 3 | Difficulty Index for items in the BECOMA On.

Item	DI
1	0.58
2	0.27
3	0.44
4	0.64
5	0.67
6	0.57
7	0.68
8	0.54
9	0.42
10	0.29
11	0.26
12	0.68
13	0.72
14	0.75
15	0.31
16	0.22
17	0.21
18	0.31
19	0.30
20	0.47
21	0.32
22	0.71
23	0.48
24	0.39
25	0.50
26	0.27
27	0.53
28	0.09
29	0.27
30	0.50
Total	0.45

Source: Authors' own work.

TABLE 4 | Descriptive statistics of the items of the BECOMA On.

Items			*f*			%			Asim.	Curt.
	M	*SD*	0	1	2	0	1	2		
1	1.35	0.84	895	690	2210	23.58	18.18	58.23	−0.72	−1.19
2	0.91	0.78	1344	1438	1013	35.42	37.89	26.69	0.15	−1.36
3	1.14	0.86	1164	954	1677	30.67	25.14	44.19	−0.26	−1.58
4	1.49	0.75	584	767	2444	15.39	20.21	64.40	−1.07	−0.38
5	1.54	0.71	493	775	2527	12.99	20.42	66.59	−1.20	−0.02
6	1.47	0.68	407	1212	2176	10.72	31.94	57.34	−0.90	−0.40
7	1.58	0.67	393	803	2599	10.36	21.16	68.48	−1.33	0.41
8	1.34	0.79	766	967	2062	20.18	25.48	54.33	−0.69	−1.08
9	1.13	0.83	1096	1124	1575	28.88	29.62	41.50	−0.24	−1.51
10	0.93	0.80	1359	1354	1082	35.81	35.68	28.51	0.13	−1.42
11	0.74	0.84	1957	859	979	51.57	22.64	25.80	0.51	−1.39
12	1.43	0.86	955	253	2587	25.16	6.67	68.17	−0.95	−0.99
13	1.61	0.72	525	436	2834	13.83	11.49	74.68	−1.51	0.62
14	1.63	0.65	356	706	2733	9.38	18.60	72.02	−1.50	0.93
15	1.03	0.77	1081	1526	1188	28.48	40.21	31.30	−0.05	−1.32
16	0.81	0.77	1547	1407	841	40.76	37.08	22.16	0.33	−1.25
17	0.80	0.76	1535	1478	782	40.45	38.95	20.61	0.35	−1.18
18	1.06	0.75	955	1647	1193	25.16	43.40	31.44	−0.10	−1.22
19	1.05	0.74	945	1723	1127	24.90	45.40	29.70	−0.08	−1.16
20	1.13	0.89	1271	743	1781	33.49	19.58	46.93	−0.26	−1.68
21	0.82	0.89	1907	655	1233	50.25	17.26	32.49	0.35	−1.65
22	1.48	0.84	862	252	2681	22.71	6.64	70.65	−1.09	−0.69
23	1.16	0.89	1243	716	1836	32.75	18.87	48.38	−0.31	−1.66
24	1.04	0.86	1340	974	1481	35.31	25.67	39.03	−0.07	−1.65
25	1.27	0.81	859	1042	1894	22.64	27.46	49.91	−0.53	−1.27
26	0.98	0.75	1117	1655	1023	29.43	43.61	26.96	0.04	−1.22
27	1.12	0.96	1544	254	1997	40.69	6.69	52.62	−0.24	−1.87
28	0.56	0.65	1996	1474	325	52.60	38.84	8.56	0.73	−0.51
29	0.98	0.75	1103	1657	1035	29.06	43.66	27.27	0.03	−1.22
30	1.27	0.81	883	1020	1892	23.27	26.88	49.86	−0.52	−1.30
Total	34.83	9.69							0.05	−0.39

Source: Authors' own work.

men and women? This study focuses on mathematics, although the same challenge applies to other disciplines such as Science, Technology and Engineering. The goal is to achieve an equal, equitable educational system that allows all students to meet the changing demands of the globalized 21st century society (Ryu et al., 2021), regardless of gender, because there is currently a gender gap in these disciplines (Kijima and Sun, 2020).

The objective of this study was to analyze the results in the BECOMA On from students in the three levels of mathematics achievement. In order to understand and conceptualize these levels of performance, the results were examined in relation to the participants' sex.

MATERIALS AND METHODS

The study used an *ex post* facto, descriptive, quantitative research methodology with the aim of describing the relationships that exist between groups of quantitative data from a series of modulating variables.

Participants

The study sample was made up of 3795 5th year primary school students, aged around 10-11 years old, from 16 regions in Spain. Each regional education authority selected the schools to participate voluntarily in the study, depending on the schools' availability to participate and them having suitable technological tools for performing the study. Instruments were applied to class groups in their usual classrooms using online devices. The distribution of the sample by sex was 2002 boys (52.75%) and 1793 girls (47.25%).

The sample was grouped by levels of performance. Based on the results, 3 similarly sized hierarchical levels were set, with 1 being the lowest and 3 being the highest performance. The levels for the BECOMA On are shown in **Table 1**.

The mean level was 1.97 (SD = 0.82), with asymmetry of.05, the distribution of the levels followed a symmetric curve, with kurtosis of -1.50, platykurtic distribution with negative excess kurtosis.

Variables

Mathematics competence was the main variable in this study. It was measured using the BECOMA On. As mentioned above, mathematics has a key role in educational processes, particularly because of its generalization to subjects' daily lives, a fundamental aspect for effective, autonomous development in society. The other variable used was the participants' sex, male (M) or female (F).

Instrument

The BECOMA On is a battery that evaluates mathematical skills in 5th year primary schoolchildren online. It is made up of 30 items spread over 7 evaluation tests: Mathematical interpretation (Items 1-5; Statistics and Probability Dimension), Mental arithmetic (Items 6-11; Arithmetic Dimension), Geometrical properties (Items 12 and 13; Geometry Dimension), Logical numerical series (Items 14-19; Arithmetic Dimension), Discovering algorithms (Items 20 and 21; Arithmetic Dimension), Conventional units (Items 22-27; Magnitudes and Proportionality Dimension), and Logical series of figures (Items 28-30; Geometry Dimension). In establishing the

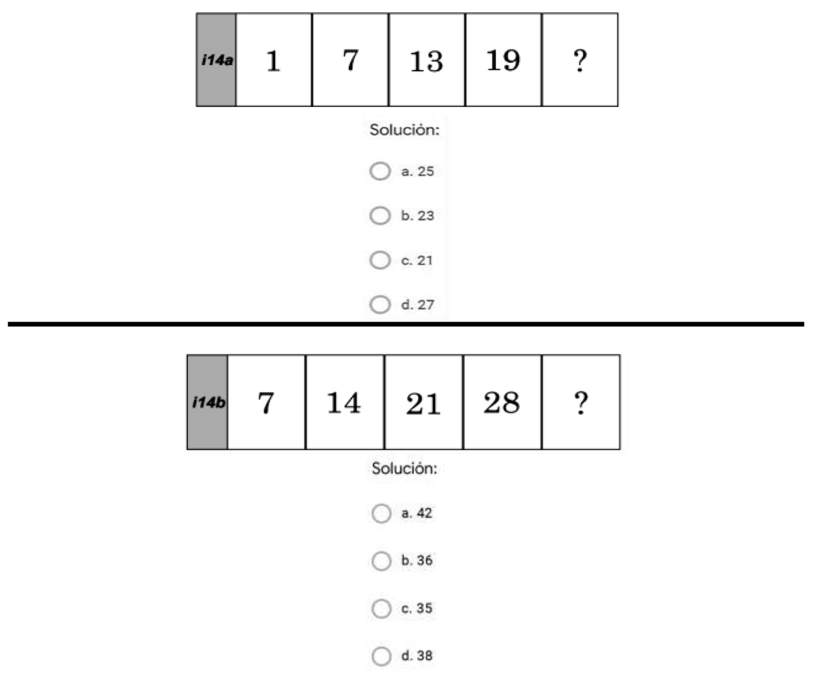

FIGURE 2 | Item 14, the easiest item in the instrument in this study. Authors' own work (2020).

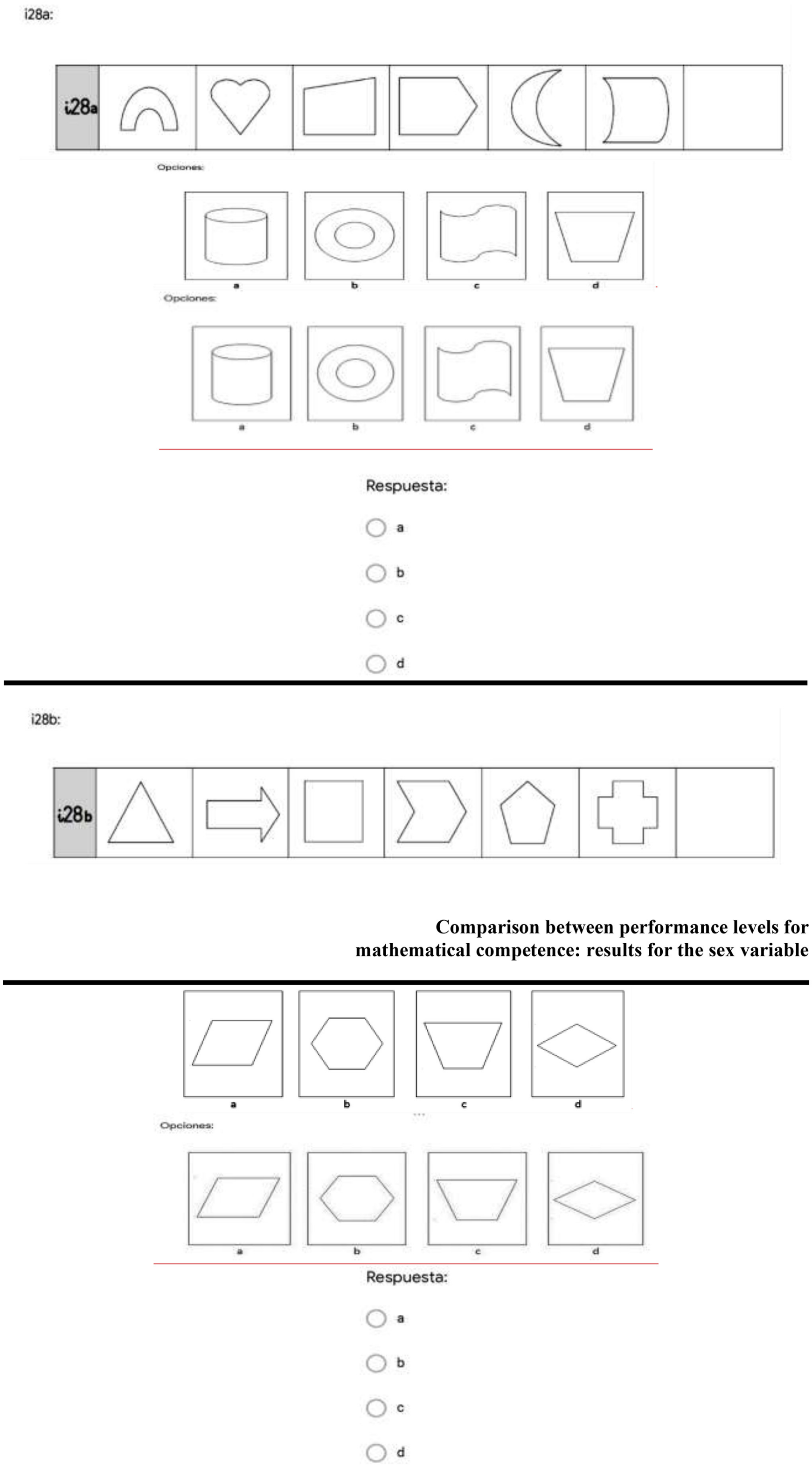

FIGURE 3 | Item 28, the most difficult item in the instrument in this study. Authors' own work (2020).

content and evaluation indicators for the items in each dimension, Royal Decree 126/2014, of February 28, which establishes the basic curriculum for Primary Education, was used as a reference (Ministerio de Educación, Cultura y Deporte, 2014c). The instrument is structured as in **Table 2**.

Each item has a possible score of 0 (wrong), 1 (partially correct), or 2 (correct), giving a possible overall minimum score of 0 and a possible overall maximum score of 60. It takes 41 minutes to do the test. In terms of statistical validity (Palomares-Ruiz and García-Perales, 2020), the instrument had a reliability index of 0.83 using Cronbach's Alpha, and validity indices between.78 and.86 (content and construct). The Difficulty Index (DI) for each item was as follows:

As **Table 3** shows, the battery had a moderate difficulty index (DI = 0.45) and appeared reactive to various levels of difficulty. Item 28 was the most difficult (DI = 0.09) while item 13 was the easiest (DI = 0.75). Item selection was judged by a group of 51 professionals in mathematics from various educational stages, giving an overall validity index for the instrument of 0.81 and a Kappa statistic of 0.82.

Procedure

A month before the data collection period, staff at each of the participating schools were given a training course covering the differential characteristics of the battery, and what they had to consider when applying it, with instructions and monitoring times. Data was collected throughout February 2019 through the online application of the instrument.

Consent was obtained from each participating student's parents or guardians for them to take part in the study, requested on the researchers' behalf by the director in each school. Subsequently, a list of children with family authorization was kept by the educational administration in each Spanish region.

TABLE 5 | Frequencies and percentages for the performance levels for each item response.

Item	1						2						3					
	0		1		2		0		1		2		0		1		2	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
1	424	11.17	331	8.72	564	14.86	280	7.38	219	5.77	764	20.13	191	5.03	140	3.69	882	23.24
2	626	16.50	496	13.07	197	5.19	448	11.81	546	14.39	269	7.09	270	7.11	396	10.43	547	14.41
3	612	16.13	348	9.17	359	9.46	381	10.04	340	8.96	542	14.28	171	4.51	266	7.01	776	20.45
4	390	10.28	396	10.43	533	14.04	151	3.98	283	7.46	829	21.84	43	1.13	88	2.32	1082	28.51
5	344	9.06	361	9.51	614	16.18	116	3.06	251	6.61	896	23.61	33	0.87	163	4.30	1017	26.80
6	307	8.09	568	14.97	444	11.70	86	2.27	405	10.67	772	20.34	14	0.37	239	6.30	960	25.30
7	308	8.12	431	11.36	580	15.28	71	1.87	238	6.27	954	25.14	14	0.37	134	3.53	1065	28.06
8	543	14.31	421	11.09	355	9.35	176	4.64	363	9.57	724	19.08	47	1.24	183	4.82	983	25.90
9	704	18.55	441	11.62	174	4.58	321	8.46	427	11.25	515	13.57	71	1.87	256	6.75	886	23.35
10	770	20.29	433	11.41	116	3.06	442	11.65	507	13.36	314	8.27	147	3.87	414	10.91	652	17.18
11	945	24.90	272	7.17	102	2.69	707	18.63	282	7.43	274	7.22	305	8.04	305	8.04	603	15.89
12	532	14.02	148	3.90	639	16.84	290	7.64	71	1.87	902	23.77	133	3.50	34	0.90	1046	27.56
13	291	7.67	224	5.90	804	21.19	163	4.30	150	3.95	950	25.03	71	1.87	62	1.63	1080	28.46
14	289	7.62	400	10.54	630	16.60	61	1.61	216	5.69	986	25.98	6	0.16	90	2.37	1117	29.43
15	717	18.89	484	12.75	118	3.11	303	7.98	623	16.42	337	8.88	61	1.61	419	11.04	733	19.31
16	812	21.40	424	11.17	83	2.19	547	14.41	512	13.49	204	5.38	188	4.95	471	12.41	554	14.60
17	794	20.92	460	12.12	65	1.71	522	13.75	563	14.84	178	4.69	219	5.77	455	11.99	539	14.20
18	638	16.81	542	14.28	139	3.66	259	6.82	638	16.81	366	9.64	58	1.53	467	12.31	688	18.13
19	631	16.63	563	14.84	125	3.29	250	6.59	674	17.76	339	8.93	64	1.69	486	12.81	663	17.47
20	574	15.13	318	8.38	427	11.25	458	12.07	259	6.82	546	14.39	239	6.30	166	4.37	808	21.29
21	820	21.61	265	6.98	234	6.17	694	18.29	219	5.77	350	9.22	393	10.36	171	4.51	649	17.10
22	536	14.12	146	3.85	637	16.79	254	6.69	85	2.24	924	24.35	72	1.90	21	0.55	1120	29.51
23	562	14.81	283	7.46	474	12.49	422	11.12	251	6.61	590	15.55	259	6.82	182	4.80	772	20.34
24	653	17.21	342	9.01	324	8.54	459	12.09	345	9.09	459	12.09	228	6.01	287	7.56	698	18.39
25	495	13.04	430	11.33	394	10.38	278	7.33	364	9.59	621	16.36	86	2.27	248	6.53	879	23.16
26	580	15.28	516	13.60	223	5.88	370	9.75	604	15.92	289	7.62	167	4.40	535	14.10	511	13.47
27	767	20.21	143	3.77	409	10.78	523	13.78	78	2.06	662	17.44	254	6.69	33	0.87	926	24.40
28	836	22.03	428	11.28	55	1.45	666	17.55	504	13.28	93	2.45	494	13.02	542	14.28	177	4.66
29	572	15.07	608	16.02	139	3.66	383	10.09	578	15.23	302	7.96	148	3.90	471	12.41	594	15.65
30	517	13.62	443	11.67	359	9.46	267	7.04	368	9.70	628	16.55	99	2.61	209	5.51	905	23.85

Source: Authors' own work.

RESULTS

Before presenting the results according to the study objectives, the descriptive statistics are presented for each item in the instrument: mean, standard deviation, frequencies and percentages.

As **Table 4** indicates, the level of difficulty can be analyzed according to the average results from each item. The easiest items were Items 4 (*M* = 1.49, *SD* = 0.75), 5 (*M* = 1.54, *SD* = 0.71), 7 (*M* = 1.58, *SD* = 0.67), 13 (*M* = 1.61, *SD* = 0.72), and 14 (*M* = 1.63, *SD* = 0.65), and the most difficult items were 11 (*M* = 0.74, *SD* = 0.84), 16 (*M* = 0.81, *SD* = 0.77), 17 (*M* = 0.80, *SD* = 0.76), 21 (*M* = 0.82, *SD* = 0.89), and 28 (*M* = 0.56, *SD* = 0.65). The mean for the battery set was 34.83 (*SD* = 9.69). **Figure 2** shows the item with the lowest difficulty level—number 14—and **Figure 3** shows the item with the highest difficulty—number 28.

In terms of asymmetry, negative scores predominated—21 of the 30 items—, in other words more values appeared to the left of the mean. In terms of kurtosis, almost all the values—27 of the 30 items and the total score—were negative, a platykurtic distribution with a lower concentration of results around the mean, an interesting aspect when analyzing different levels of performance according to the results.

The results are presented based on the study objectives, first the results in the BECOMA On for the three performance levels and then the descriptive statistics. Following that, each level is examined in relation to sex.

Table 5 shows the results in the BECOMA On for the three performance levels. The frequency and percentages for each

TABLE 6 | ANOVA Test comparing performance levels.

Item	1		2		3		*F*	*df*	*p*	Eta^2	Direction
	M	*SD*	*M*	*SD*	*M*	*SD*					
1	1.11	0.86	1.38	0.82	1.57	0.75	104.44	3794	0.000***	0.05	1 < 2 < 3
2	0.67	0.72	0.86	0.74	1.23	0.79	177.49	3794	0.000***	0.09	1 < 2 < 3
3	0.81	0.84	1.13	0.85	1.50	0.73	231.38	3794	0.000***	0.11	1 < 2 < 3
4	1.11	0.83	1.54	0.70	1.86	0.44	385.76	3794	0.000***	0.17	1 < 2 < 3
5	1.20	0.83	1.62	0.65	1.81	0.46	275.77	3794	0.000***	0.13	1 < 2 < 3
6	1.10	0.75	1.54	0.62	1.78	0.44	390.02	3794	0.000***	0.17	1 < 2 < 3
7	1.21	0.79	1.70	0.57	1.87	0.37	406.32	3794	0.000***	0.18	1 < 2 < 3
8	0.86	0.81	1.43	0.72	1.77	0.50	560.44	3794	0.000***	0.23	1 < 2 < 3
9	0.60	0.71	1.15	0.80	1.67	0.58	735.85	3794	0.000***	0.28	1 < 2 < 3
10	0.50	0.65	0.90	0.77	1.42	0.70	527.96	3794	0.000***	0.22	1 < 2 < 3
11	0.36	0.62	0.66	0.81	1.25	0.83	443.07	3794	0.000***	0.19	1 < 2 < 3
12	1.08	0.94	1.48	0.84	1.75	0.64	216.11	3794	0.000***	0.10	1 < 2 < 3
13	1.39	0.82	1.62	0.70	1.83	0.51	128.86	3794	0.000***	0.06	1 < 2 < 3
14	1.26	0.79	1.73	0.54	1.92	0.29	427.39	3794	0.000***	0.18	1 < 2 < 3
15	0.55	0.65	1.03	0.71	1.55	0.59	749.88	3794	0.000***	0.28	1 < 2 < 3
16	0.45	0.61	0.73	0.72	1.30	0.72	505.69	3794	0.000***	0.21	1 < 2 < 3
17	0.45	0.59	0.73	0.69	1.26	0.74	471.40	3794	0.000***	0.20	1 < 2 < 3
18	0.62	0.67	1.08	0.70	1.52	0.59	595.95	3794	0.000***	0.24	1 < 2 < 3
19	0.62	0.65	1.07	0.68	1.49	0.60	586.50	3794	0.000***	0.24	1 < 2 < 3
20	0.89	0.86	1.07	0.89	1.47	0.80	151.60	3794	0.000***	0.07	1 < 2 < 3
21	0.56	0.78	0.73	0.87	1.21	0.90	200.13	3794	0.000***	0.09	1 < 2 < 3
22	1.08	0.94	1.53	0.81	1.86	0.49	330.72	3794	0.000***	0.15	1 < 2 < 3
23	0.93	0.88	1.13	0.89	1.42	0.82	102.04	3794	0.000***	0.05	1 < 2 < 3
24	0.75	0.82	1.00	0.85	1.39	0.78	192.01	3794	0.000***	0.09	1 < 2 < 3
25	0.92	0.82	1.27	0.80	1.65	0.61	299.49	3794	0.000***	0.14	1 < 2 < 3
26	0.73	0.73	0.94	0.72	1.28	0.69	192.52	3794	0.000***	0.09	1 < 2 < 3
27	0.73	0.90	1.11	0.96	1.55	0.82	267.18	3794	0.000***	0.12	1 < 2 < 3
28	0.41	0.57	0.55	0.63	0.74	0.70	86.91	3794	0.000***	0.04	1 < 2 < 3
29	0.67	0.66	0.94	0.73	1.37	0.69	321.88	3794	0.000***	0.14	1 < 2 < 3
30	0.88	0.81	1.29	0.79	1.66	0.62	348.70	3794	0.000***	0.15	1 < 2 < 3
Total	24.49	4.67	34.93	2.58	45.97	4.76	8553.78	3794	0.000***	0.82	1 < 2 < 3

** Significant at 5% ($p < 0.05$).*
***Significant at 1% ($p < 0.01$), and*
****Significant at 0.01% ($p < 0.001$).*
Source: Authors' own work (2020).

performance level are given. There were 1319 students (34.76%) in level 1, 1263 (33.28%) in level 2 and 1213 (31.96%) in level 3.

Table 5 gives the totals for each level and response option. In the mean results for all items, 15.45% of the students were in level 1 and scored 0, 10.25% were in level 1 and scored 1, and 9.06% were in level 1 and scored 2; 9.09% of students were in level 2 and scored 0, 9.63% were in level 2 and scored 1, and 14.56% were in level 2 and scored 2; 3.99% of the students were in level 3 and scored 0, 6.97% were in level 3 and scored 1, and 21.01% were in level 3 and scored 2. Level 1 and 2 student responses were more erratic and reflected a clear difference between levels. To determine statistically significant differences, **Table 6** shows the means, standard deviations and the results of the ANOVA test.

The students in level 1 had a mean score of 24.49 (*SD* = 4.67), in level 2 the mean score was 34.93 (*SD* = 2.58), and in level 3 it was 45.97 (*SD* = 4.76). The students in level 3 had higher mean scores in all items. Furthermore, the differences between levels were statistically significant in all items, $p < 0.001$, with the level 3 students scoring higher. To complete the characterization of these three groups of students, another variable, students' sex, was used for comparison between levels.

The sex distribution of the original sample of 3795 students was 2002 boys (52.75%) and 1793 girls (47.25%). The mean score in the instrument for boys was 35.18 (*SD* = 10.08) and for girls it was 34.44 (*SD* = 9.22), with a *p*-Value < 0.05. To more closely examine the significance of the differences between the sexes, the results were analyzed according to each level of performance. The frequencies and percentages for each sex in each of the three levels are given below.

At level 1 performance, there was little difference in the proportions for each score (**Table 7**): 23.12% of the responses were boys scoring 0, 15.68% were boys scoring 1, and 13.21% were boys scoring 2; 21.33% of the responses were girls scoring 0, 13.80% were girls scoring 1, and 12.86% were girls scoring 2.

TABLE 7 | Frequencies and percentages by sex from students with level 1 performance.

Item	Boys						Girls					
	0		1		2		0		1		2	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
1	234	17.74	181	13.72	271	20.55	190	14.40	150	11.37	293	22.21
2	331	25.09	261	19.79	94	7.13	295	22.37	235	17.82	103	7.81
3	334	25.32	169	12.81	183	13.87	278	21.08	179	13.57	176	13.34
4	195	14.78	219	16.60	272	20.62	195	14.78	177	13.42	261	19.79
5	178	13.50	196	14.86	312	23.65	166	12.59	165	12.51	302	22.90
6	167	12.66	293	22.21	226	17.13	140	10.61	275	20.85	218	16.53
7	170	12.89	243	18.42	273	20.70	138	10.46	188	14.25	307	23.28
8	301	22.82	218	16.53	167	12.66	242	18.35	203	15.39	188	14.25
9	359	27.22	228	17.29	99	7.51	345	26.16	213	16.15	75	5.69
10	391	29.64	241	18.27	54	4.09	379	28.73	192	14.56	62	4.70
11	491	37.23	147	11.14	48	3.64	454	34.42	125	9.48	54	4.09
12	291	22.06	86	6.52	309	23.43	241	18.27	62	4.70	330	25.02
13	155	11.75	127	9.63	404	30.63	136	10.31	97	7.35	400	30.33
14	161	12.21	217	16.45	308	23.35	128	9.70	183	13.87	322	24.41
15	365	27.67	246	18.65	75	5.69	352	26.69	238	18.04	43	3.26
16	403	30.55	233	17.66	50	3.79	409	31.01	191	14.48	33	2.50
17	428	32.45	219	16.60	39	2.96	366	27.75	241	18.27	26	1.97
18	315	23.88	293	22.21	78	5.91	323	24.49	249	18.88	61	4.62
19	321	24.34	291	22.06	74	5.61	310	23.50	272	20.62	51	3.87
20	284	21.53	172	13.04	230	17.44	290	21.99	146	11.07	197	14.94
21	428	32.45	142	10.77	116	8.79	392	29.72	123	9.33	118	8.95
22	262	19.86	84	6.37	340	25.78	274	20.77	62	4.70	297	22.52
23	298	22.59	152	11.52	236	17.89	264	20.02	131	9.93	238	18.04
24	349	26.46	171	12.96	166	12.59	304	23.05	171	12.96	158	11.98
25	267	20.24	225	17.06	194	14.71	228	17.29	205	15.54	200	15.16
26	294	22.29	279	21.15	113	8.57	286	21.68	237	17.97	110	8.34
27	376	28.51	77	5.84	233	17.66	391	29.64	66	5.00	176	13.34
28	432	32.75	227	17.21	27	2.05	404	30.63	201	15.24	28	2.12
29	291	22.06	330	25.02	65	4.93	281	21.30	278	21.08	74	5.61
30	278	21.08	236	17.89	172	13.04	239	18.12	207	15.69	187	14.18

Source: Authors' own work.

Looking at the frequencies of scores of 2 for both sexes, there were differences. There were more boys scoring 2 in items 15 (boys 5.69% and girls 3.26%), 20 (boys 17.44% and girls 14.94%), 22 (boys 25.78% and girls 22.52%), and 27 (boys 17.66% and girls 13.34%). More girls scored 2 in items 1 (boys 20.55% and girls 22.21%), 7 (boys 20.70% and girls 23.28%), 8 (boys 12.66% and girls 14.25%), and 12 (boys 23.43% and girls 25.02%).

For the level 2 students, the frequencies and percentages for each response option were as follows (**Table 8**):

At level 2 the results were similar to level 1 in terms of sex, with small differences between boys and girls. 13.53% of responses were boys scoring 0, 14.98% were boys scoring 1, and 21.84% were boys scoring 2; 13.78% were girls scoring 0, 13.95% were girls scoring 1, and 21.91% were girls scoring 3. Looking at the frequencies of scores of 2 for each item, there were also differences between the sexes. More boys scored 2 in items 15 (boys 16.94% and girls 9.74%), 17 (boys 8.71% and girls 5.38%), 18 (boys 16.31% and girls 12.67%), and 19 (boys 15.04% and girls 11.80%). More girls scored 2 in items 7 (boys 35.79% and girls 39.75%), 8 (boys 26.68% and girls 30.64%), 23 (boys 21.06% and girls 25.65%), and 30 (boys 22.33% and girls 27.40%).

For the level 3 students, the frequencies and percentages for each response option were as follows (**Table 9**):

At level 3 there were greater differences between the sexes, with boys scoring higher than girls. 6.78% of responses were boys scoring 0, 11.89% were boys scoring 1, and 37.38% were boys scoring 2; 5.70% of responses were girls scoring 0, 9.91% were girls scoring 1, and 28.33% were girls scoring 2. Looking at the scores of 2 for each item, there were large differences between the sexes. This was notable in items 15 (boys 39.57% and girls 20.86%), 19 (boys 34.05% and girls 20.61%), 22 (boys 53.01% and girls 39.32%) and 27 (boys 44.44% and girls 31.90%). At this level, the differences were smaller in items 3 (boys 34.46% and girls 29.51%), 26 (boys

TABLE 8 | Frequencies and percentages by sex from students with level 2 performance.

Item	Boys						Girls					
	0		1		2		0		1		2	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
1	137	10.85	104	8.23	395	31.27	143	11.32	115	9.11	369	29.22
2	224	17.74	279	22.09	133	10.53	224	17.74	267	21.14	136	10.77
3	206	16.31	161	12.75	269	21.30	175	13.86	179	14.17	273	21.62
4	82	6.49	156	12.35	398	31.51	69	5.46	127	10.06	431	34.13
5	80	6.33	130	10.29	426	33.73	36	2.85	121	9.58	470	37.21
6	37	2.93	224	17.74	375	29.69	49	3.88	181	14.33	397	31.43
7	45	3.56	139	11.01	452	35.79	26	2.06	99	7.84	502	39.75
8	103	8.16	196	15.52	337	26.68	73	5.78	167	13.22	387	30.64
9	151	11.96	214	16.94	271	21.46	170	13.46	213	16.86	244	19.32
10	221	17.50	256	20.27	159	12.59	221	17.50	251	19.87	155	12.27
11	364	28.82	153	12.11	119	9.42	343	27.16	129	10.21	155	12.27
12	160	12.67	41	3.25	435	34.44	130	10.29	30	2.38	467	36.98
13	89	7.05	89	7.05	458	36.26	74	5.86	61	4.83	492	38.95
14	33	2.61	108	8.55	495	39.19	28	2.22	108	8.55	491	38.88
15	129	10.21	293	23.20	214	16.94	174	13.78	330	26.13	123	9.74
16	240	19.00	279	22.09	117	9.26	307	24.31	233	18.45	87	6.89
17	242	19.16	284	22.49	110	8.71	280	22.17	279	22.09	68	5.38
18	102	8.08	328	25.97	206	16.31	157	12.43	310	24.54	160	12.67
19	109	8.63	337	26.68	190	15.04	141	11.16	337	26.68	149	11.80
20	219	17.34	147	11.64	270	21.38	239	18.92	112	8.87	276	21.85
21	340	26.92	122	9.66	174	13.78	354	28.03	97	7.68	176	13.94
22	112	8.87	53	4.20	471	37.29	142	11.24	32	2.53	453	35.87
23	241	19.08	129	10.21	266	21.06	181	14.33	122	9.66	324	25.65
24	223	17.66	170	13.46	243	19.24	236	18.69	175	13.86	216	17.10
25	116	9.18	191	15.12	329	26.05	162	12.83	173	13.70	292	23.12
26	172	13.62	318	25.18	146	11.56	198	15.68	286	22.64	143	11.32
27	246	19.48	41	3.25	349	27.63	277	21.93	37	2.93	313	24.78
28	351	27.79	231	18.29	54	4.28	315	24.94	273	21.62	39	3.09
29	203	16.07	299	23.67	134	10.61	180	14.25	279	22.09	168	13.30
30	150	11.88	204	16.15	282	22.33	117	9.26	164	12.98	346	27.40

Source: Authors' own work.

TABLE 9 | Frequencies and percentages by sex from students with level 3 performance.

Item	Boys						Girls					
	0		1		2		0		1		2	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%	*f*	%
1	127	10.47	71	5.85	482	39.74	64	5.28	69	5.69	400	32.98
2	155	12.78	213	17.56	312	25.72	115	9.48	183	15.09	235	19.37
3	100	8.24	162	13.36	418	34.46	71	5.85	104	8.57	358	29.51
4	24	1.98	46	3.79	610	50.29	19	1.57	42	3.46	472	38.91
5	15	1.24	89	7.34	576	47.49	18	1.48	74	6.10	441	36.36
6	7	0.58	143	11.79	530	43.69	7	0.58	96	7.91	430	35.45
7	8	0.66	86	7.09	586	48.31	6	0.49	48	3.96	479	39.49
8	28	2.31	106	8.74	546	45.01	19	1.57	77	6.35	437	36.03
9	43	3.54	140	11.54	497	40.97	28	2.31	116	9.56	389	32.07
10	89	7.34	223	18.38	368	30.34	58	4.78	191	15.75	284	23.41
11	166	13.69	165	13.60	349	28.77	139	11.46	140	11.54	254	20.94
12	76	6.27	25	2.06	579	47.73	57	4.70	9	0.74	467	38.50
13	46	3.79	38	3.13	596	49.13	25	2.06	24	1.98	484	39.90
14	2	0.16	49	4.04	629	51.85	4	0.33	41	3.38	488	40.23
15	20	1.65	180	14.84	480	39.57	41	3.38	239	19.70	253	20.86
16	77	6.35	253	20.86	350	28.85	111	9.15	218	17.97	204	16.82
17	99	8.16	237	19.54	344	28.36	120	9.89	218	17.97	195	16.08
18	25	2.06	243	20.03	412	33.97	33	2.72	224	18.47	276	22.75
19	25	2.06	242	19.95	413	34.05	39	3.22	244	20.12	250	20.61
20	126	10.39	90	7.42	464	38.25	113	9.32	76	6.27	344	28.36
21	209	17.23	91	7.50	380	31.33	184	15.17	80	6.60	269	22.18
22	25	2.06	12	0.99	643	53.01	47	3.87	9	0.74	477	39.32
23	156	12.86	104	8.57	420	34.62	103	8.49	78	6.43	352	29.02
24	128	10.55	147	12.12	405	33.39	100	8.24	140	11.54	293	24.15
25	39	3.22	134	11.05	507	41.80	47	3.87	114	9.40	372	30.67
26	81	6.68	308	25.39	291	23.99	86	7.09	227	18.71	220	18.14
27	124	10.22	17	1.40	539	44.44	130	10.72	16	1.32	387	31.90
28	289	23.83	298	24.57	93	7.67	205	16.90	244	20.12	84	6.92
29	94	7.75	277	22.84	309	25.47	54	4.45	194	15.99	285	23.50
30	66	5.44	138	11.38	476	39.24	33	2.72	71	5.85	429	35.37

Source: Authors' own work.

23.99% and girls 18.14%), 28 (boys 7.67% and girls 6.92%), 29 (boys 25.47% and girls 23.50%) and 30 (boys 39.24% and girls 35.37%). There were no items in which more girls scored 2 than boys.

Once the frequencies were established for each level by sex, a *t*-test was performed to determine whether there were statistically significant differences according to sex. The results are given in **Table 10**.

TABLE 10 | *t*-Test by sex between performance levels 1, 2, and 3.

Sex	1		2		3		*t*	*df*	*p*
	f	%	*f*	%	*f*	%			
Male	686	18.08	636	16.76	680	17.92	-1.99	3793	0.040*
Female	633	16.68	627	16.52	533	14.04			

*Significant at 5% ($p < 0.05$).
**Significant at 1% ($p < 0.01$), and
***Significant at 0.01% ($p < 0.001$).
Source: Authors' own work (2020).

As **Table 10** shows, there were statistically significant differences at $p < 0.05$. This significance was due to an unequal frequency between the sexes at performance level 3, where there were 680 boys (17.92%) and 533 girls (14.04%). In the other two levels, 1 and 2, the results were more similar, level 1 included 686 (18.08%) boys and 633 (16.68%) girls, while level 2 included 636 boys (16.76%) and 627 girls (16.52%). According to statistics from the Ministry for Education (Ministerio de Educación y Formación Profesional, 2020) for non-university education in school year 2018/19 (the most recent available data), of the 35494 students identified as highly capable, 23092 were boys (65.06%), and 12402 were girls (34.94%). This reflects a continuing disparity between the sexes in the identification of highly capable students, with the diagnostic process being detrimental to girls. This indicates an inequality in education and the need to examine causal factors more deeply.

DISCUSSION

Society's scientific and technological progress requires highly qualified professionals (Frey and Osborne, 2017) as there are constant innovations and shifting requirements (Macià and Garreta, 2018). Schools are fundamental in developing students' talents (Mandelman et al., 2010). The most recent Spanish education laws address educational needs, and addressing and adapting to students' needs from the very beginnings of schooling is fundamental. Equality and innovation promote quality and social development (Organization for Economic Cooperation, and Development, 2019a), and evaluation and research help monitor them in order to establish educational policies (Schleicher, 2018; Harju-Luukkainen et al., 2020).

This study focused on the analysis of mathematics skills in the three groups of students identified by performance following the application of the BECOMA On, an instrument with high indices of reliability and validity. Understanding the potential of the students in these three levels is of significant social and educational interest and understanding the complexity of the mathematical approaches and strategies they use in problem solving is fundamental (Jaime and Gutiérrez, 2017). Initially, the results were as expected, students in the highest level—3—demonstrated better results and assessments than students in levels 1 and 2. What is interesting is the presence of various statistically significant differences.

Just over a third, 1319 students (34.76%), were identified as belonging to performance level 1, 1263 (33.28%) to level 2 and 1213 (31.96%) to level 3. Comparing the results of these three groups, statistically significant differences were found, $p < 0.001$; level 3 students had higher scores in all of the items in the instrument. Level 3 students were the most capable in mathematics. It is important to consider the processes for identifying these highly capable students. From time to time, unfortunately, their potentials, needs, and interests seem to be neglected in the learning and teaching process, and occasionally there are various serious adaptation problems (Pomar et al., 2009; García-Perales and Almeida, 2019).

To complete the characterization of these three groups of students, the levels were compared in relation to students' sex. In the study, 52.75% of the participating sample were boys and 47.25% girls. In performance levels 1 and 2, there were few discrepancies in performance between the sexes, with varying differences in favor of one sex or the other. However, at level 3, there were greater differences, and it was the boys who had the highest scores in all items. Boys in level 3 had 6.78% of responses scoring 0, 11.89% scoring 1, and 37.38% scoring 2. For the girls in level 3, the percentages were 5.70%, 9.91% and 28.33% for scores of 0, 1, and 2 respectively. This resulted in statistically significant differences, $p < 0.05$, since at performance level 3 or higher, there were 680 boys (17.92%) compared to 533 girls (14.04%). This reflects a continuing disparity between the sexes in the higher achievement levels for Mathematics, also seen in other research (Baye and Monseur, 2016; Hyde, 2016; Ministerio de Educación y Formación Profesional, 2019), demonstrating an inequality in education and the need to examine causal factors in depth (Calvo, 2018).

In short, the instrument used is functional and original because it establishes a relationship between assessment and mathematical and digital skills. Its close connection with the Spanish school curriculum for the 5th grade of primary education gives it a valuable practical component for use in developing educational practices. The detection of learning needs and potentials, in this case for mathematics using online evaluation, is key because of mathematics' instrumental and interdisciplinary nature, and it opens up an interesting path for the generalization and application of such instruments.

CONCLUSION

Schools must develop educational practices that allow inclusive, quality education for all (Franco et al., 2017; Arnaiz-Sánchez et al., 2018, 2020). Educational administrations must ensure all students achieve functional and meaningful learning, making it a priority to support the existence of equitable, democratic schooling adjusted to each student's needs and characteristics. Educational policies must be directed toward achieving this end. In this regard, it is essential to consider all the variables that influence the teaching and learning processes, including student sex (Hadjar et al., 2014; Farfán and Simón, 2017; Palomares-Ruiz and García-Perales, 2020), with a view to rethinking actions to foster improvement in academic performance and to promote innovation in education.

As noted in the introduction, biological factors, such as intelligence or certain personality traits, and contextual factors, such as stereotypes and the family itself, may explain differences between the sexes in mathematical performance, especially at higher performance levels. In this regard, analyzing the contexts in which boys and girls socialize is fundamental for studying these differences between the sexes (Hadjar et al., 2014; Mizala et al., 2015; Palomares-Ruiz and García-Perales, 2020), an issue that should be approached from various perspectives (Del Río et al., 2016). In addition, the differences between the sexes highlight the need to rethink educational practices from the perspective of equality and innovation, trying to prevent mathematical learning from leading to academic and professional segregation (Cantoral et al., 2014). In this regard, working on STEAM skills (Science, Technology, Engineering, Arts and Mathematics) may be a useful approach for promoting coeducation and gender equality in education (UNESCO, 2019; Ryu et al., 2021), including non-formal education (Juvera and Hernández-López, 2021), and may be generalizable to highly capable mathematics students (García-Perales and Almeida, 2019). Teacher training in teaching mathematics is especially important (Monroy and Marroquín, 2020) and is a key aspect for teaching and learning in the other STEAM fields (Román-Graván et al., 2020; Hernández-Barco et al., 2021; Ortiz-Revilla and Greca, 2021), in which women are underrepresented (Lehman et al., 2017; Botella et al., 2019; McCullough, 2020).

The large sample participating in this study underlines the importance of using ability tests for diagnostic processes, in this case for Mathematics. The generalization of specific activities for any schoolchild, whatever their abilities, means starting a process of educational adaptation and individualization (Díez and Jiménez, 2018; Torres, 2018). Currently, educational processes are characterized by their complexity and multidimensionality, with multiple factors that can have an impact on teaching and learning as part of mathematics teaching (Palomares-Ruiz and García-Perales, 2020). For this reason, it would be advisable to expand the variables of analysis in future studies with BECOMA On, and include variables such as academic performance, teachers' and students' perceptions of students' interest in and motivation for mathematics, and whether highly capable students are detected. In addition, future studies will seek to generalize the application of this instrument to other educational levels, the sex of the students will be a fundamental variable. Generalizing studies for this variable to other educational levels would add weight to the results from this study. In addition, attempts will be made to perform repeated-measure replication study designs, similar to those used in other studies, using the written version of this instrument (García-Perales et al., 2020, 2021). Identifying any student's potential for mathematics helps to offer an individualized educational response, which is a priority of inclusive, high-quality education.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Before the study began, written informed consent to participate in this study was provided by the regional administration of each school. These educational institutions did require written informed consent from the parents. We ensured the anonymity of the responses and the confidentiality of all data collected, with published results not containing any school identifying information.

AUTHOR CONTRIBUTIONS

RG designed the study, collected and analyzed the data, and wrote the manuscript. AP contributed to the interpretation of the data and wrote, revised, and refined the manuscript. RG and AP have participated in sending the article to the journal. Both authors contributed to the article and approved the submitted version.

FUNDING

The study was supported economically by the Castilla-La Mancha Regional Government (JCCM) and the European Regional Development Fund (FEDER) [Project Reference/Code SBPLY/19/180501/000149]. It has also had the support of the National Institute of Educational Technologies and Teacher Training (INTEF), the National University of Distance Education (UNED), and the University of Castilla-La Mancha (UCLM).

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 04 August 2021
doi: 10.3389/fpsyg.2021.659009

Detailed Emotional Profile of Secondary Education Students Toward Learning Physics and Chemistry

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The present research arises from the need to identify the emotions that K-7 to K-10 students experience toward the learning of Physics and Chemistry, since it is a fact that there is a decrease in the number of students choosing itineraries related to Science. Different blocks of contents have been considered in each subject in order to identify emotions toward each one of them. The considered sample consisted of 149 K-8 students, 152 K-9 students and 130 K-10 students from several middle and high schools in Badajoz (Spain) during the 2014–2015 school year. Students experienced more positive emotions toward the content of Chemistry than toward those of Physics. A decrease was detected in the mean frequency of positive emotions such as joy, fun, and tranquility from K-8 to K-10, as well as an increase in negative emotions such as boredom, anxiety, disgust, fear, nervousness, worry, and sadness. It has also been found that positive emotions toward Chemistry contents are mainly related to teachers' methods and attitudes, while negative emotions toward Physics contents are related to the exclusive use of the textbook, solving Physics problems, or giving oral presentations of the topics in class.

Keywords: emotions, Principal Component Analysis, pupils, Secondary Education, Physics and Chemistry, content, teacher

OPEN ACCESS

Edited by:
Jin Su Jeong,
University of Extremadura, Spain

Reviewed by:
Yuvaraj Rajamanickam,
Nanyang Technological University, Singapore
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *26 January 2021*
Accepted: *25 May 2021*
Published: *04 August 2021*

Citation:
Dávila-Acedo MA, Airado-Rodríguez D, Cañada-Cañada F and Sánchez-Martín J (2021) Detailed Emotional Profile of Secondary Education Students Toward Learning Physics and Chemistry. Front. Psychol. 12:659009. doi: 10.3389/fpsyg.2021.659009

INTRODUCTION

Nowadays the concept of sustainability has reached dimensions beyond the simple environmental care and includes sociological, economic, ethical, or cultural dimensions (Zamora-Polo and Sánchez-Martín, 2019). The birth of this comprehensive vision of sustainability is intimately linked with the promulgation of the Sustainable Development Goals (General Assembly of United Nations, 2015). Considering this holistic vision of sustainability, the training of students supposes a key aspect for change, in the construction and implementation of a way of understanding sustainability from the cognitive, the emotional, the civic, and the sociocultural dimensions.

Education has been traditionally situated in the center of sustainable human development, and in this regard, science education plays a key role. There are no doubts of the existence of clear interrelationships between experimental sciences and the questions of civic responsibility or of citizenship at a planetary scale. In this line, few disciplines are as closely related to the classical idea of sustainability as science teaching (Colucci-Gray et al., 2013). Scientific literacy is a must to form responsible citizens and this formation needs to be carried out in the school, making the introduction of sciences and STEM areas in general in the curriculum crucial at all educational stages.

Hargreaves (2000) stated more than 20 years ago that in the teaching-learning process the cognitive dimension is influenced by the affective one and vice versa. Numerous studies point in the direction that both cognitive and affective aspects influence the teaching and learning processes (Alsop and Watts, 2003; Hargreaves, 2003; Shapiro, 2010). Results indicate that teachers who ignore the affective aspects of learning might be limiting conceptual change in their pupils (Duit and Treagust, 2012; Chiang and Liu, 2014). Pintrich et al. (1993) had already questioned the so-called "cold change" and defended the importance of motivation and emotions as determining factors in science learning. According to Tobin (2012) and Tomas and Ritchie (2012), emotions are a central part of the action of learning science, and they act as a social glue that interconnects individual and collective interests and actions. Emotions are also linked to action, decision-making (Damasio, 2010), and academic achievement (Pekrun and Linnenbrink-García, 2014; Goetz et al., 2016), which turns especially important for pupils, when at the end of their compulsory education, they have to decide about their future studies. Knowledge of pupils' emotions toward the science, specifically toward Physics and Chemistry, would help teachers to properly plan the teaching and learning process to make it more effective and attractive for their pupils (Cheung, 2011). Therefore, science is not sustainable if taught and learned from assumptions that do not contemplate the affective domain.

Garritz (2010) pointed out that traditionally science has been mainly represented in schools as an area of the rational, analytical curriculum, with hardly any relation to emotions. For years, social, cultural, and emotional factors have been excluded, being labeled by the dominant positivist orientations as improper or unscientific, being contrary to the objectivity of science (Alsop and Watts, 2003).

Learning science is much more than a cognitive process because, in order to learn, it is necessary to be able to do and to want to do (Bacete and Betoret, 2000). If, as pointed out by Bisquerra (2009), academic knowledge is learnt better when the pupils have emotional competencies then it is necessary to analyze both the cognitive and the affective aspects of learning different scientific content. Diagnoses of the emotions that occur every day in secondary classrooms will therefore provide a basis for intervention in the improvement of science learning by designing activities that promote more positive emotions (King et al., 2015), since positive emotions foster learning whereas negative emotions limit the ability to learn (Pekrun, 1992).

The concept of emotion has been studied in various lines of research from different perspectives. They all show that it is a complex process which analyses the subjective reactions to a situation or personal event which entails both physiological and behavioral changes (Bisquerra, 2009; Kelchtermans and Deketelaere, 2016). There are many taxonomies for the classification of emotions. Namely, focusing on their effects upon behavior (Bisquerra, 2009), two types of emotions can be distinguished: Positive and negative. Positive emotions produce pleasant feelings, with short temporal duration, and negative emotions produce unpleasant feelings and the mobilization of many resources to face them. Other authors such as Posner et al. (2005) have proposed models based on the interaction between the intensity of emotions or the level of activation of the individual (excitation/relaxation) and the assessment of the situation which involves these emotions (pleasant/unpleasant).

Nonetheless, as pointed out by Tomas and Ritchie (2012), there have still only been a few studies focused on the role of emotions in the learning of specific science content. It is therefore essential to continue in this line and to deep into the identification of the influence of emotions in the learning of the different contents of the science curriculum (Garritz, 2010).

Research shows that K-1 to K-6 pupils usually have positive emotions and attitudes toward science (Mellado et al., 2014) but that these decrease with age, especially by K-8 to K-10 (Osborne et al., 2003). During K-7 to K-10 levels, the emotions toward science depend on the content (Borrachero et al., 2014), with more positive attitudes toward Biology and Geology than to Physics and Chemistry.

K-7 to K-10 students' positive emotions toward particular science content are related to self-efficacy, or the belief in their own ability and competence to learn that content. Self-efficacy is closely related to self-regulation, and it is a powerful variable which enables the prediction of students' achievement (Cakiroglu et al., 2012). Borrachero et al. (2014) showed that when the students felt that they were able to learn certain content they showed an increase in their positive emotions toward that content. But when they did not feel capable of learning the content, they more often experienced negative emotions. This is especially important in Physics and Chemistry for which more negative emotions are recorded and self-efficacy has most influence (Brígido et al., 2013).

Attitudinal and emotional depression toward sciences is attributed to the fact that K-7 to K-10 students create an image of school science as boring, difficult, overly theoretical, and of little use. Other causes that might have an influence are the teacher, the lack of practical work, or the excessive orientation in the classes to preparing for examinations (Murphy and Beggs, 2003).

In any case, as acknowledged by Wan and Lee (2017), more studies are needed to deal with the analysis of the causal relationships between the cognitive and the affective dimensions in K-7 to K-10 levels when learning sciences.

RESEARCH OBJECTIVE

The present research aims to achieve the following objectives:

1. To determine and to analyze the relationship between the positive and negative emotions experienced by K-8, K-9 and K-10 students when receiving Physics and Chemistry lessons.

2. To determine and to analyze the relationship between certain aspects related to teacher and student and their possible implication as causes of positive or negative emotions toward Physics and Chemistry.

METHODOLOGY

Sample

The process carried out to select participants was cluster sampling. This provided a representative sample of Secondary Education (K-8 to K-10) of a city with about 150,000 inhabitants like the city of Badajoz (Spain), where the study has been carried out. Access and convenience sampling have been the implemented inclusion criteria, looking for a homogeneous distribution throughout the city.

The considered sample consisted of 431 students, according to the distribution summarized in **Table 1**.

Sociodemographically the sample featured 47.1% girls and 52.9% boys with ages ranging between 13 and 17 years old. It is an urban sample, with participant students belonging to middle-class families and working parents.

Instrument

A quantitative non-experimental or "*ex post* facto" methodological approach was considered to perform this research. The data acquisition instrument was a questionnaire of the authors' own elaboration (**Supplementary Material**), based on the one previously proposed by Borrachero et al. (2014).

In the questionnaire, students are asked first about negative and positive emotions they experience when learning certain topics belonging to five blocks of contents. Those blocks of contents were established according to the current educational curriculum (*Real Decreto 83/2007*). Namely, the considered blocks of content were "Matter" (block I), "Energy and Electricity" (block II), "Structure and Changes of Matter" (block III), "Kinematics and Dynamics" (block IV) and "Work and Energy" (block V). Blocks I, II, and III were considered in K-8 to K-10, while blocks IV and V were exclusively considered for K-10 students; secondly, they are asked about the felt emotions toward several aspects related to the teacher and the students; and lastly, they are asked how often they feel seven positive and seven negative emotions when learning Physics and Chemistry. Previous research carried out by our research group allowed us to identify the selected emotions as the most representative in the academic field (Brígido et al., 2013; Borrachero et al., 2014). In all cases students are asked to respond according to an 11-points Likert scale (0 = minimum; 10 = maximum).

TABLE 1 | Distribution of students by level.

Level	Number of students	Percentage (%)
K-8	149	36.4
K-9	152	35.3
K-10	130	30.2

The reliability of the questionnaire was calculated using the covariation between the items of the different scales making it up in order to verify its internal consistency. The obtained values were all higher than 0.80, which means that the questionnaire is quite good.

Procedure

The teachers responsible for the K-8 to K-10 levels were asked to hand out the questionnaires to the different groups of students. Data was processed and analyzed statistically using the statistical package SPSS (Statistical Product and Service Solutions) 22.0 and The Unscrambler for Windows.

A Principal Component Analysis (PCA) was performed in order to establish possible correlations between the variables, in this case content (of Physics and Chemistry) and causes (teacher/pupil).

Principal component analysis is a dimensionality reduction technique that has proven to be useful in the extraction of relevant information from complex datasets. This analysis seeks to maximize the variance of a linear combination of the variables. It maps each instance of the given dataset in a d-dimensional space to a k-dimensional subspace so that $k < d$. The set of k new dimensions are called the principal components (PC) and each principal component is directed toward a maximum variance excluding the variance already accounted for in all the preceding components. The first principal component is the linear combination with maximal variance. The second principal component is the linear combination with maximal variance in a direction orthogonal to the first principal component, etc. The first principal component also represents the line that minimizes the total sum of squared perpendicular distances from the points to the line. The principal components can be represented as:

$$PC_i = a_1X_1 + a_2X_2 + ... + a_dX_d \tag{1}$$

where:

PC_i: principal component "i";

X_j: original feature "j";

a_j: numerical coefficient for X_j.

Van der Wal and Kowalczyk (2013) worked in the measurement of changes in the emotional state of a speaker by analyzing his/her voice and employed PCA to visualize the results to the speaker in the 2-d space. They reported that PCA is a promising technique for visualizing a human's emotional state. Zhang and Zhao (2013) assayed and compared different dimensionality reduction methods, including PCA, with an aim of improving the performance on spoken emotion recognition.

PCA has been also commonly employed in the field of psychology. For instance, Gray studied the implications of psychological membership in the classroom for achievement motivation and emotions (Gray, 2017). Kroeger et al. (2017) employed PCA for the evaluation of impulsivity and emotion dysregulation in adolescents with borderline personality disorder; and Gondim et al. (2015) employed it to analyze measurements on individual differences in the regulation of emotions.

RESULTS AND DISCUSSION

This section describes the results obtained after performing the descriptive analysis of the emotions experienced by K-8 to K-10 students when learning Physics and Chemistry content. Results are presented according to the two proposed research objectives.

Emotions of K-8 to K-10 Students Toward the Learning of Physics and Chemistry. Relationship Between Emotions (Positive and Negative)

Figure 1 shows the mean frequencies (Likert scale from 0 to 10) for positive emotions experienced by K-8 to K-10 students when learning Physics and Chemistry, depending on the level. The mean frequency ranges between 4.5 and 6.9. Maxima values are found for K-8 students, namely for emotions joy (6.78), satisfaction (6.42), and tranquility (6.26).

It can be also observed that K-8–K-10 students experienced a decrease in the average frequency of the positive emotions as joy, trust, fun, enthusiasm, and tranquility from K-8 to K-10.

A Student's t-test was performed and statistically significant differences were found in the positive emotions joy (p = 0.000), trust (p = 0.045), fun (p = 0.000), and tranquility (p = 0.000) between K-8 and the other two levels, which reveals a significant decrease from K-8 to higher levels.

Figure 2 shows the mean frequencies (Likert scale from 0 to 10) for negative emotions experienced by K-8–K-10 students when learning Physics and Chemistry, depending on the level. In this case, the mean frequency for negative emotions ranges between 3 and 7, with maxima in K-10 for boredom (6.25), nervousness (6.02), and worry (6.71). This might be due to the higher amount of Physics contents in K-10, whereas more Chemistry is taught in K-9.

Also, it can be observed that negative emotions such as boredom, anxiety, disgust, fear, nervousness, worry, and sadness increase in the average frequency from K-8 to K-10.

Statistical analysis of the mean frequencies reveals significant differences in boredom (p = 0.000), anxiety (p = 0.010), disgust (p = 0.002), fear (p = 0.000), nervousness (p = 0.014), worry (p = 0.000), and sadness (p = 0.003) between K-10 and the other two levels.

Results were also analyzed by PCA. Firstly, the KMO (Kaiser-Mayer-Olkin) index was calculated and the Bartlett's sphericity test was applied in order to check the suitability of the considered sample (N = 431) to be analyzed by PCA. When applying Bartlett's sphericity test a p-value < 0.05 is obtained and a high ($\approx$1) KMO index is calculated, which means that PCA can be efficiently performed in the current dataset, i.e., fourteen emotions measured in three levels K-8–K-10.

Results of PCA are summarized in **Figures 3**, **4** in the form of loadings and scores plots, respectively, and subsequently discussed.

Figure 3 shows the loadings plot for the plane formed by the first (PC1) and the second (PC2) principal components, which as stated above, explain 35.97 and 18.51% of total variance, respectively. This plot helps to identify correlations among variables. As it can be observed, the emotions enthusiasm, joy, satisfaction, fun, and trust present high loading values for PC1, which means that this PC represents positive emotions. It can also be observed that in the in the plane formed by PC1 and PC2 these emotions are located close to each other, which means that they are positively correlated. Nevertheless, the emotions tranquility and surprise are located apart from the other positive emotions in the plane formed by PC1 and PC2, showing lower loading values for PC1. The small loading values for emotions tranquility and surprise suggest that these emotions might not be further considered in the interpretation of the results, since they contribute in a small extension in PC1 and PC2. On the other hand, the emotions fear, worry, nervousness, sadness, and anxiety present high values of loading for PC2 and they are located close to each other in the plane formed by PC1 and PC2, which means that PC2 represents negative emotions and that the emotions above listed are positively correlated among them. The emotions boredom and disgust are located a bit farther from the cluster formed by the other negative emotions. However, since these two emotions present lower loading values for PC2, it can be concluded that the are not very important in the interpretation of the results. In the plot it can be also observed that both groups of emotions are negatively correlated.

The scores plot for the plane formed by PC1 and PC2 is represented in **Figure 4**. This plot helps in the identification of sample clusters and it helps also to visualize how different are sample constituents among them. In this case, as it can be observed, there is no a clear separation between students of the different levels.

To sum up, a decrease has been detected in the mean frequency of all the positive emotions and an increase in all the negative emotions from K-8 to K-10. These results can be compared to the ones obtained by Dávila et al. (2016) with a similar sample in which a decrease in the frequency of positive emotions (joy, confidence, happiness, tranquility, surprise, and excitement), and an increase in the negative emotions (worry, shame, disgust, and anger) was detected from K-9 to K-10.

The decrease in the positive and increase in the negative emotions in middle and high school in these subjects agrees with the decline of positive attitudes toward science stated in previous studies (Osborne et al., 2003). The combination of negative attitudes and emotions toward Physics and Chemistry content can influence the choice of subsequent career paths and university degrees that involve these subjects (Custodio et al., 2013) since emotions are fundamental in decision making (Angie et al., 2011). The decrease, observed in many countries, in the number of students pursuing Chemistry degrees, and even more in the case of Physics degrees, might be related to the emotionally difficult context surrounding science learning during their secondary education, when they did not manage to enjoy learning these subjects (Vázquez and Manassero, 2008).

Finally, unlike other studies (Borrachero et al., 2014), in the present one, differences according the gender were not found for any of the considered dimensions.

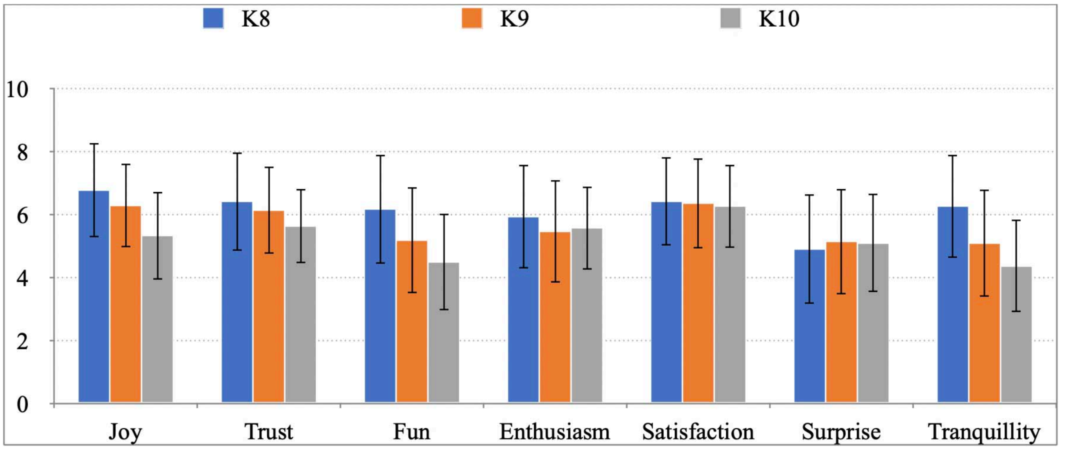

FIGURE 1 | Mean frequency of positive emotions experienced by secondary pupils when learning Physics and Chemistry depending on the course.

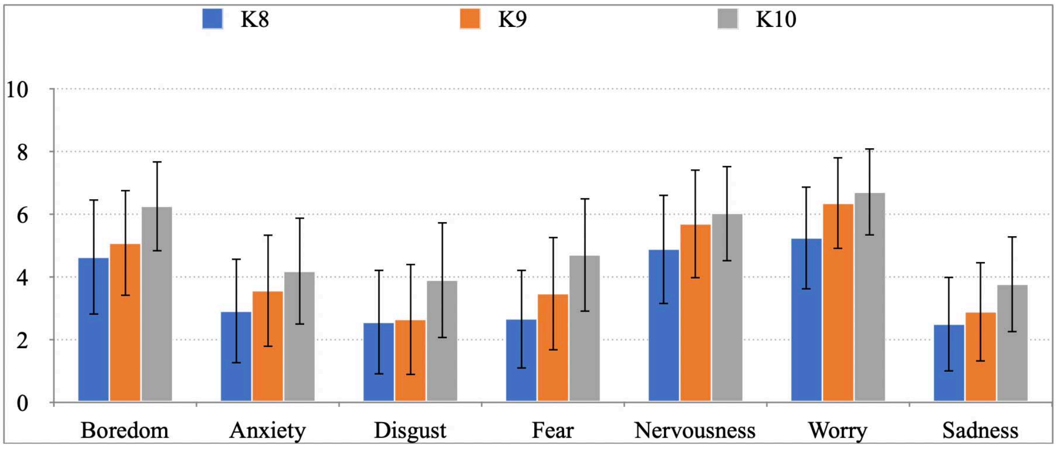

FIGURE 2 | Mean frequency of negative emotions experienced by secondary pupils when learning Physics and Chemistry depending on the course.

Relationship Between the Considered Aspects Related to Teacher and Students With Positive Emotions

The part of the dataset containing measures of positive emotions toward Physics and Chemistry content, as well as toward the causes related to the teacher's evaluation, attitude, and methods, and toward aspects related to the students, such as their ability to learn, motivation to learn, and grades obtained, was also analyzed by PCA. **Figure 5** shows the loadings for the first two principal components (PC1 vs. PC2), which explain 76 and 6% of the total variance of the system, respectively. As stated above, the loadings plot resulting from a PCA is particularly useful to detect correlations between variables. Those variables with a high loading on a particular principal component (PC) define the meaning of that PC. To determine the correlation between variables, one must bear in mind that when two variables have high loadings on the same PC, those variables are strongly correlated. If the loadings of the two variables have the same sign then the correlation is positive, and negative if they have different signs.

Considering only the distribution of the various items of the content on the loadings map, it is observed that items 1–15 are grouped in the high part of the first principal component (PC1, horizontal axis), whereas items 16–23 are grouped in the high part of the second principal component (PC2, vertical axis). As items 1–15 are Chemistry content, and items 16–23 correspond to Physics content, the first conclusion that could be reached, given these variables grouping, is that the two disciplines cause in the students different quantities and types of positive emotions, which would contribute to the decoupling of the two disciplines with regard to the students' emotions. It can also be said that all the Physics items considered in the study are strongly correlated, with this correlation being positive as they were all grouped in the high part of PC2, and that all the Chemistry items were also correlated positively with each other, being grouped in the high part of PC1. Thus, for instance, the students who show positive emotions toward the

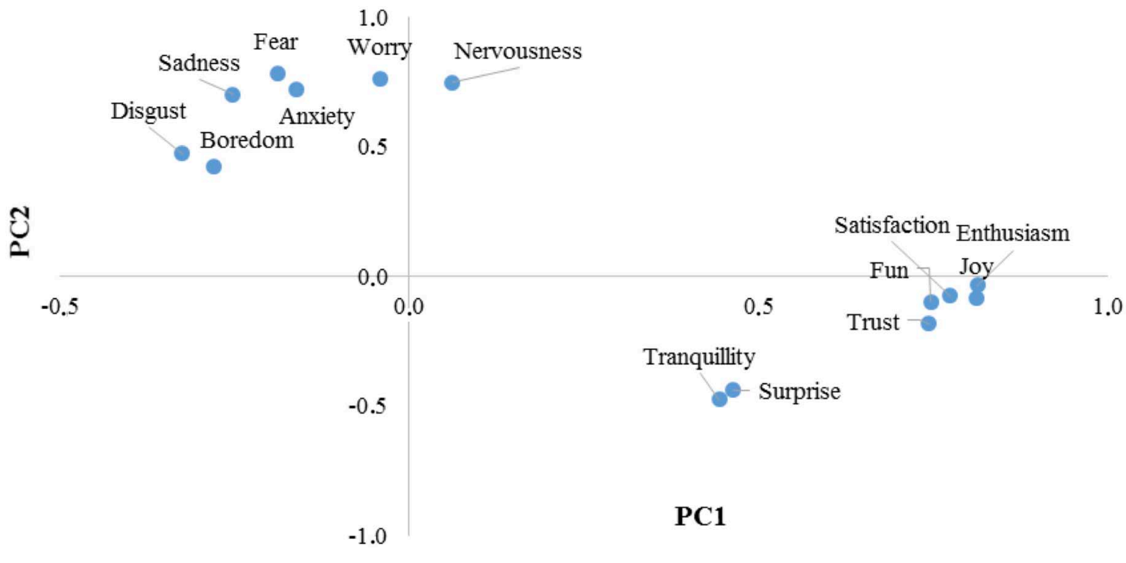

FIGURE 3 | Results of the PCA on emotions of K-8 to K-10 students toward the learning of Physics and Chemistry: loadings plot for PC1 and PC2.

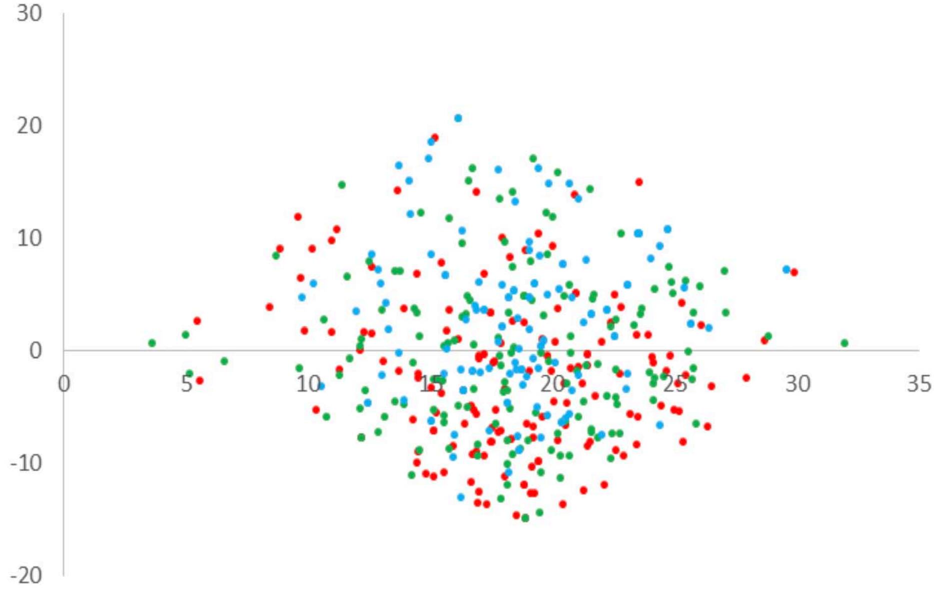

FIGURE 4 | Results of the PCA on emotions of K-8 to K-10 students toward the learning of Physics and Chemistry: scores plot for PC1 and PC2 (red points: K-8; green points: K-9; blue points: K-10).

item "Atoms and molecules" (I1) also show them to the items "The periodic table and periodic properties of the elements" (I11), "Formulation and nomenclature" (I12), and "Chemical reactions and stoichiometry" (I13). Considering not only the items but also the distribution of the various causes studied related with the teacher (pink dots), one observes that all these causes except P3 ("Exclusive use of the textbook") are in the high part of PC1, very close to the cluster formed by the Chemistry items. This means that these causes of positive emotions related to the teacher are correlated positively with the Chemistry items. For example, a pupil showing positive emotions toward Chemistry items will also show positive emotions toward aspects related with the teacher's methods, such as doing practical laboratory activities (P1), group work and activities outside the classroom (P2), as well as to aspects related with the teacher's attitude, such as clarification and resolution of doubts (P6), and the use of new technologies (ICT) (P7). It is logical that pupils with positive emotions toward lab work or activities outside the classroom usually do not show such emotions toward the exclusive use of textbooks (P3).

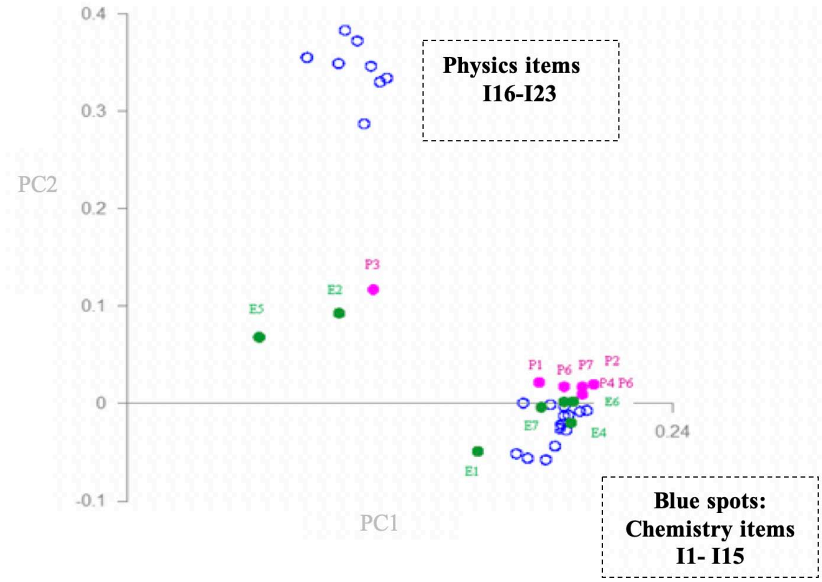

FIGURE 5 | Results of the PCA on considered aspects related to teacher and students and positive emotions: Loadings plot for the principal components 1 and 2.

Considering also the causes related to the students (green dots), one observes that all of them except two are located within or very near the cluster formed by the Chemistry content. The two exceptions are E2 ("Giving oral presentations in class") and E5 ("Solving physics problems"). It is logical that solving Physics problems correlates with neither the Chemistry content nor oral presentations since this is something scarcely worked during this educational stage. Again, this means that all the considered causes related to students which have been considered in this study except E2 and E5 are positively correlated with the Chemistry content as far as positive emotions are concerned. In view of these results, it can be affirmed that a pupil with positive emotions toward the Chemistry content also shows them toward aspects related to motivation and the capacity to learn, such as relating the content to daily life (E3), using diagrams to understand the content (E7), and participating in science-related debates (E4). As shown in the plot, the correlation of E1 ("Marks obtained") with the Chemistry content is weaker than that of E3, E4, E6, and E7, probably because facing an evaluation creates uncertainty and fear in the students, regardless of the subject. Regarding the Physics items in this study, no clear correlations were observed with any of the considered aspects related to the teacher or to the students.

The scores plot of the performed PCA on positive emotions and aspects related to teacher and students is represented in **Figure 6**. The score of a sample on a particular PC describes the characteristics of that sample for the variables with high loadings on that PC. Thus, samples with similar scores on the same PC can be said to be similar with respect to the variables that most contribute to that PC. The score plot is typically used to detect groupings, similarities, and differences between samples.

As it can be observed in **Figure 6** most of the samples are clustered along the high part of the horizontal axis (PC1), as Chemistry topics and the causes related to the teacher and the students commented above. This means that most students expressed positive emotions toward the Chemistry content and toward the teacher- and pupil-related causes correlated with that content. But, since the maximum density of points is located in this part of the plot, one can also state that most of the positive emotions expressed by the pupils were toward the content of Chemistry, not Physics, because the density of points at the high part of PC2 is very low.

It is reported in the literature that emotions toward learning content are related to the strategies and activities undertaken in class. King et al. (2015) found that, when classes include stimulating activities and experiments about energy, the students' emotions were very positive: Amazement, surprise, joy, and happiness. In a study with secondary pupils on physics content, Folashade and Akinbobola (2009) found that the use of methods which encourage the pupils' active participation, such as a problem-based learning technique, leads to a better understanding of physics concepts as well as increasing the pupils' confidence, especially for those who show low capacities for learning that content.

In the frame of the current research, internal and external causes could be related to the considered students' and the teachers' aspect, respectively. However, the failure attributed to internal causes led to lower self-esteem than the failure attributed to external causes. In the current research, the pupils attributed their negative emotions toward physics content to the use of the textbook in class. In contrast, they attributed positive emotions to themselves when solving a physics problem or giving oral presentations. In the case of chemistry content, the pupils who experienced positive emotions attribute them to aspects related to their ability and motivation to learn. The negative emotions, however, were attributed to the teacher's methods and attitude.

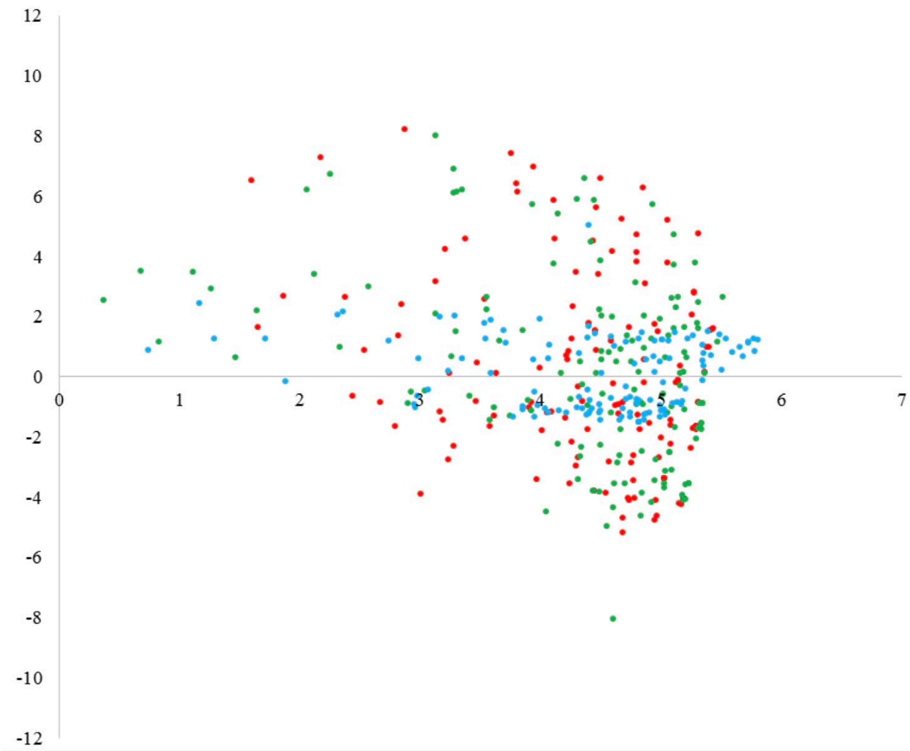

FIGURE 6 | Results of the PCA on considered aspects related to teacher and students and positive emotions: Score plot for the principal components 1 and 2 (red points: K-8; green points: K-9; blue points: K-10).

CONCLUSION AND IMPLICATIONS

As the first conclusion of the current study it can be stated that teachers could design and use different teaching strategies so that their pupils could participate actively to interact in their learning and thus promote the development of positive emotions. In the following paragraphs, it is given a synthesis of the reached main conclusions based on the two research objectives initially posed for the study.

Regarding the first objective, statistically significant differences were found in the mean frequency of the emotions (both positive and negative) experienced by students according to their level.

Thus, in learning Physics and Chemistry, K-8–K-10 students experienced a decrease in the mean frequency of positive emotions such as joy, fun, and tranquility from K-8 to K-10. At the same time, there is an increase in the mean frequency of the negative emotions such as boredom, disgust, fear, and sadness from K-8 to K-10. This is very worrying for science learning, since K-10 is crucial for many students as it is the end of compulsory education in the Spanish system.

Regarding the second objective, one can state that there is a correlation between the topics of the Chemistry content and aspects related to the teacher's methods and attitude, such as performing practical laboratory activities, group work and activities outside the classroom, clarification and resolution of doubts, and the use of new technologies, as well as aspects related to the pupils' motivation and ability to learn, especially considering the relation and usefulness of the content with everyday life, the use of diagrams to understand and learn the topics of the content, and their memorization.

In addition, there is a correlation between the topics of the Physics content and aspects related to the teacher's methods such as the exclusive use of the textbook, as well as aspects related to the pupils' motivation and capacity to learn, such as problem solving and giving oral presentations.

Therefore, these negative emotions are not only due to the content or topic, but might also correspond to the teachers themselves or the way they teach (Daschmann et al., 2014). Sometimes teachers use the same methods or models with which they themselves were taught, focusing exclusively on the transmission of knowledge, and taking no notice of the emotional aspects that should be considered in the process of teaching and learning.

Regarding the implications, it is necessary to study the affective domain in the subject of Physics and Chemistry, and to foster the development of positive attitudes by promoting favorable feelings and emotions in order to improve students' expectations toward this subject. It is necessary to generate positive emotions toward the teaching and learning of Physics and Chemistry, and to address the negative emotions acquired during the years at school (Mellado et al., 2014). Therefore, it is also necessary for teachers to be able to detect these emotions in their everyday work in class (Rahayu, 2015; King et al., 2017), and the use of different teaching strategies for their pupils to actively participate and interact in their learning, emerges as a must, so that students are able to appreciate the usefulness of the content of Physics and Chemistry in their daily lives.

Many studies on emotions reported in the literature are focused in the transition between primary and secondary education and most of these studies are made with university students and therefore these studies are based in the memory (Brígido et al., 2013; Borrachero et al., 2014). In this article we present a novel study which is pioneer in the fact that emotions and their causes have been monitored *in situ*, in the secondary education classroom.

Teachers are crucial in generating emotionally positive environments (Olitshy and Milne, 2012) because, as Kangas et al. (2017) noted, the success of the learning environment during secondary education, in terms of the student's satisfaction, depends largely on the teacher's commitment and teaching decisions. Therefore, teachers have to be aware of their own emotions, as these can have an impact on the pupils themselves (Melo et al., 2017).

It is a fact that STEM areas in general are not popular among secondary students, and it is causing a decline in scientific vocations and even an insufficient scientific literacy in the population. To solve the problem, it is necessary in first place to look for the cause. With the approach presented in this article it is shown that the methodology employed by teachers constitutes a main cause of negative emotions toward the considered disciplines. The identification of the methodology as a cause of negative emotions is in a way good news, since it implies that the solution to the problems and changing the situation is in hands of the teachers. It is stated in the literature that the implementation of innovative, motivating, and collaborative activities in secondary education science classes increases motivation, interest, and positive emotions (Ritchie et al., 2011; Tomas and Ritchie, 2012). Our research group has demonstrated, for instance, how the implementation of active, motivating, and innovative methodologies improves attitude and emotions toward scientific disciplines and definitely it is demonstrated that emotions are implied in what the student learns (Sánchez-Martín et al., 2020; Hernández-Barco et al., 2021; Yllana et al., 2021).

Future research will be to design an intervention program based on the development of practical classroom activities associated with specific content. The aim will be to improve the cognitive and emotional components of learning by motivating K-8–K-10 students in their science classes, creating confidence, helping them to understand the content, using technological resources, arousing their interest, and, in combining individual and cooperative work, favoring teacher-student and student-student interaction (Laukenmann et al., 2010; Bellocchi et al., 2013; Bellocchi and Ritchie, 2015; King et al., 2017; Sánchez-Martín et al., 2017; Jeong et al., 2019). In the future, it would be also interesting to consider new sampling strategies that allow continuous, instead of punctual, monitorization of emotions. Finally, the generation of qualitative data based on an adapted version of the elaborated questionnaires and even by means of semi-structured interviews constitutes a natural path of continuity of the presented research.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Commission of Bioethics and Biosecurity of the University of Extremadura. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

This work was funded by the research project EDU2016-77007-R (AEI/ERDF, EU), and research projects: GR18004 and IB18004 (Junta de Extremadura and the European Regional Development Fund).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.659009/full#supplementary-material

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frontiers in Psychology

ORIGINAL RESEARCH
published: 10 August 2021
doi: 10.3389/fpsyg.2021.669855

A STEM Course Analysis During COVID-19: A Comparison Study in Performance and Affective Domain of PSTs Between F2F and F2S Flipped Classroom

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OPEN ACCESS

Edited by:
Douglas F. Kauffman, Medical University of the Americas—Nevis, United States

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Chung Kwan Lo, The Education University of Hong Kong, China
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Andreas Hartinger, University of Augsburg, Germany

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *19 February 2021*
Accepted: *15 July 2021*
Published: *10 August 2021*

Citation:
Jeong JS and González-Gómez D (2021) A STEM Course Analysis During COVID-19: A Comparison Study in Performance and Affective Domain of PSTs Between F2F and F2S Flipped Classroom. Front. Psychol. 12:669855. doi: 10.3389/fpsyg.2021.669855

Due to the worldwide COVID-19 pandemic, university education has faced a significant challenge that requires adaptation to virtual and online education. Here, a fruitful flipped methodology with increased popularity can support adaption to and improvement of the current pandemic situation. This research presents a comparison of two different instruction situations with an identical teaching methodology, face-to-face (F2F) and face-to-screen (F2S) flipped methodology, in terms of students' performance and affective domain in a science, technology, engineering and mathematics (STEM) course. It was considered and designed as an examination of 132 pre-service teachers (PSTs), with 68 and 64 PSTs respectively for each group. The first group before the pandemic was applied by F2F flipped classroom and the second group after the pandemic was applied by F2S flipped classroom. The results after pertaining various data analyses of class activities and questionaries showed that performance had been improved for both groups toward the course. In addition, F2F had a significant difference in PSTs' emotion and perception toward the course and made classes more interactive. The mean score values of students' emotion and perception between two groups showed that the difference between these mean values were significant, suggesting a very large effect. Particularly, the effect size (ES) showed that positive emotions were more significant with different variables and the items Q7–Q9 of questionnaires indicated more significant different perceptions for both F2F and F2S after completing the course. Finally, the principal component analysis (PCA) test described that F2F answers were located mainly in the positive emotion, while F2S answers were grouped in the negative emotion, while no differences were observed for PSTs perceptions to the flipped methodology. Consequently, although F2F–F2S transition was an effective process, instructors and PSTs faced difficulties in the platform usage for online lectures reflecting emotions' results in F2S group. Thus, by solving the problems raised, it will allow PSTs to be more interactive in a virtual and online context for their future implementation by giving them active instruction methodology and educating future students to teach STEM contents.

Keywords: STEM education, COVID-19, flipped classroom, F2F and F2S, e-learning, emotion and perception, performance

INTRODUCTION

Due to the COVID-19 pandemic, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) indicated that educational institutions had been providing over 70% of their classes and assessments through various on-line and virtual platforms (Stub, 2020; UNESCO, 2020). Before the appearance of COVID-19, e-learning showed a consistent tendency of continuous growing, about 15.4% per year, in educational institutions (Wang et al., 2020). There was not any pressure or uncertainty for either institutions or students (Azeiteiro et al., 2015; Garg and Jain, 2017). However, learning environments were forced to change due to circumstances during the COVID-19 pandemic, which saw millions of cases confirmed in more than 216 countries according to the World Health Organization (WHO) (Cao et al., 2020; WHO, 2020a,b). The situation that began in the middle of the spring semester was totally unexpected and unplanned for by all people working in academic institutions, especially instructors and students. Due to precautious actions before the COVID-19 spread and lockdown, many institutions had already switched to complete e-learning teaching/learning (Cao et al., 2020; Crawford et al., 2020; WHO, 2020b). So, it resulted in a suspension of the current educational procedures and developments in many worldwide institutions (Fauci et al., 2020; WHO, 2020a). The traditional instruction method was changed to an e-learning model that allowed students to continue and finish their classes and activities (Crawford et al., 2020). Each institute adopted different and various e-learning systems due to the action of social distance regulation and directives, which the WHO strongly recommended to halt the COVID-19 spread amongst persons and countries (WHO, 2020a,b). Previous studies have indicated that instructors and students in educational areas had a close relationship and improvements in the on-line and virtual system (Moura et al., 2010; Azeiteiro et al., 2014; Islas-Pérez et al., 2015). However, this new and unfamiliar home-based education system was implemented to foster instructors and students to have a considerable responsibility of on-line and virtual skills and experiences (Bacelar-Nicolau et al., 2009; Crawford et al., 2020). Despite the enormous efforts to solve the glitches among the different teaching strategies implemented, the efficiency of on-line and virtual teaching was still falling behind expectations (Zare et al., 2016; Yang et al., 2017). Even though the instructors had undergone the training required in a brief period, there was a requirement to change the existing and paper-based materials to on-line and virtual teaching resources (Parkes et al., 2014; Cao et al., 2020). Therefore, it would be necessary to find out a proper methodology and system, which could achieve its objectives in education accomplishing the WHO social distancing suggestion during the COVID-19 pandemic.

In a teaching-learning process, especially considering current situations, on-line and virtual learning can be considered as a proper educational model (Eneroth, 2000; Paechter et al., 2010). This model, along with the information and communication technologies (ICTs), allows flexible and relevant student-focused education in science, technology, engineering, and mathematics (STEM) education (Pereira et al., 2008; Shee and Wang, 2008; Chujitarom and Piriyasurawong, 2019). ICTs can provide scaffolding among teacher to teacher, teacher to student, and student to student interactions that can help on-line and virtual systems as a virtual teaching-learning platform and multi-faceted communications (Garrison, 2000; Narciss et al., 2007; Pereira et al., 2008). The on-line and virtual system has various advantages that can be used without the consideration of time and place and can require a self-regulated learning practice (Garrison, 2000; Lee and Lee, 2008; Lozano et al., 2013). In teaching-learning forming fundamental factors for STEM education, it can be considered as inter- and multi-disciplinary development (Narciss et al., 2007; Lee and Lee, 2008; Lozano et al., 2013). According to Hansen (2001), the students in an on-line and virtual system typically had a greater sense of comprehension and experience, which led to fruitful transformative teaching-learning (Arbaugh, 2000; Schramm et al., 2001). Also, the students' achievements for learning as Paechter et al. (2010) indicated were closely connected to the on-line and virtual systems' characteristics, which were multi-directional communications for learning strategy flexibility and experience transmission, related with all significant issues of STEM education (Narciss et al., 2007; Moura et al., 2010; Lambrechts et al., 2018). On the other hand, these innovative systems proposed could be of great help for STEM education development in long-term teaching-learning (Garrison, 2000; Azeiteiro et al., 2014). Here, the technological integration to STEM education could fill a current educational niche, although there are many existing challenges, which will be integrated to transformational STEM teaching-learning (Pavlova, 2013; McVey, 2016; Nowotny et al., 2018). However, general on-line and virtual learning systems are still required to examine more specific models' efficiency in-depth, such as higher STEM education through e-learning systems (McVey, 2016; Nowotny et al., 2018). Thus, active methodologies based on on-line and virtual system are necessary to achieve their objectives in adopting STEM education during COVID-19.

The flipped classroom methodology, a form of active education methodology, recently gained a great level of attention in higher education along with the STEM courses (Roach, 2014; Blair et al., 2016; Ye et al., 2018). This methodology can provide a more suitable teaching-learning environment to reach significant and fruitful achievements together with the great availability of digital materials that comply with the WHO social distancing suggestion during the COVID-19 pandemic (Roach, 2014; Blair et al., 2016; Cao et al., 2020). In the view of students, O'Flaherty and Phillips (2015) indicated that this methodology required them to take responsibility for their learning. Sams and Bergmann (2013) mentioned that a flipped classroom course would be effective not only for a big group of students but also for individual students, unlike a traditional direct lecture. Particularly, in higher STEM education, traditional teaching methodology was better suited as an instructor-centered methodology to be delivered to students (Williams et al., 2018; Jeong and González-Gómez, 2020a). Here, the flipped classroom methodology aforementioned can be an effective and alternative approach delivering a student-centered methodology (Dooley et al., 2018; Zamora-Polo et al., 2019; Jeong and González-Gómez, 2021). In a basic flipped course setting, students can receive their lectures at home in the format of videos, tasks, quizzes, and written materials in on-line spaces such as Moodle. Reversely, students can do class activities that are conventionally done at home with instructors' supervision (Jeong and González-Gómez, 2020b). Here, more student-centered activities can be performed in-class time along with providing just-in-time lectures and collaborative tasks, which can address detailed questions, and realize more efficient chances for learning (Mattis, 2015; Moraros et al., 2015; Namaziandost and Çakmak, 2020). For this research, the performance in the flipped classroom methodology can be improved in the context of students' learning due to there being more in-class time along with active learning (Akçayir and Akçayir, 2018; Jeong and González-Gómez, 2020a). Kemp and Grieve (2014) indicated in their study that similar academic performance was achieved in both an on-line and face-to-face learning environment, but a higher preference of face-to-face settings was observed when students-centered activities were carried out. Although learning and affective domains could be considered as interdependent, the affective domains' influence on learning should be theoretically analyzed and practically investigated (Bower, 1981; Schwarz, 1990; Abele, 1995; Hascher and Edlinger, 2009). The learning process is the outcome of the cognitive and affective domain interplay (Pintrich et al., 1993). Currently, several theories show at least a certain amount of empirical evidence. Bower (1981) indicated a theory, "mood-congruence-hypothesis," that information can be more easily remembered in a positive mood than in a negative mood. Thus, Schwarz (1990) suggested the theory "mood as information," in which the pertainable point is the role that mood itself plays for learners. STEM education research was prevailing in the cognitive aspects of teaching/learning procedures without attention on the affective domain (Mellado et al., 2014). However, a growing interest has been seen on understanding the influence of emotions in the teaching/learning process by many studies in recent years (Dos Santos and Mortimer, 2003; Zembylas, 2007; Abrahams, 2009; Ritchie et al., 2011; Schutz and Zembylas, 2011; Bellocchi et al., 2013). Owing to support and higher interest in affective domain, students' perception can be analyzed for their opinions of flipped classroom methodology (Blair et al., 2016; Akçayir and Akçayir, 2018). Many studies have been carried out in different educational levels that have measured the students' perceptions toward the flipped classroom methodology (Bishop and Verleger, 2013; Roach, 2014; Gilboy et al., 2015; Sowa and Thorsen, 2015; Long et al., 2016). Abele (1995) demonstrated a positive mood can even increase the pace of perception along with performance and processing. Jeong et al. (2019) showed that perception and emotion had a significant relationship to students' learning in various learning environments in a STEM course, including face-to-face and face-to-screen learning settings, particularly the confirmation of more face-to-face education with different researchers (Marshall, 2011; Baker, 2012; Blair et al., 2016; Williams et al., 2018; Ye et al., 2018). The instruction methodology should also encourage students' positive perceptions and emotions toward STEM, especially in pre-service teachers (Osborne et al., 2003; Jarvis and Pell, 2004), who will be future instructors after their development and formation. Hence, based on the previous literatures and reasons confirmed, an active flipped methodology can be evaluated in different situations, face-to-face (F2F) and face-to-screen (F2S) flipped methodology in a STEM course, due to COVID-19, in terms of the students' performance and affective domains.

TABLE 1 | The comparison of demographic background information between PSTs participating in the F2F and F2S flipped classroom study.

Items		F2F Group	F2S Group
Number of PSTs		68	64
Average age		20.1	21.0
Gender	Male	35.1%	54.0%
	Female	64.9%	46.0%
Pre-test GPA (Maximum 10)		6.93	6.91
Educational background	Social sciences	68.3%	65%
	Sciences	14.5%	20%
	Technology	1.8%	0%
	Arts	5.1%	5%
	Others	10.3%	10%

In this work, a comparison of two different instruction situations along with an identical teaching methodology is presented: F2F and F2S flipped methodology in terms of PSTs' performance and emotion and perception in a STEM course. A total of 132 PSTs participated in this study across two different years, 2018/19 and 2019/2020 course (68 and 64 PSTs, respectively). Students were randomly assigned to the studied group and they agreed to participated in this study. Particularly, before and after the COVID-19 pandemic, the first group was applied to the F2F flipped classroom and second group was applied to the F2S flipped classroom. With the various data analyses of class activities and questionaries, the results expose the performance variation and the significant change of emotion and perception of PSTs toward the course implemented. Also, it can show their effect size (ES) and principal component analysis (PCA) differences based on PSTs' data that allow PSTs to be more interactive and adopted in different instruction contexts.

MATERIALS AND METHODS

A flipped classroom instruction methodology was applied in a STEM class during two different courses with an identical instruction methodology before and after the COVID-19 pandemic. Precisely, a F2F flipped instruction methodology was followed in the first course and F2S flipped instruction methodology in the second one. The class used to study this methodology had a course syllabus containing overall themes of science along with the didactic method and strategies to teach these contents for primary education. For each course, PSTs were randomly assigned and agreed to participate in this research.

Sample

For the course proposed, a total of 141 PSTs from two groups enrolled for this course. The PSTs were randomly assigned into individual courses, 70 and 71 PSTs, respectively. Here, the PSTs before registering for the subject did not have any knowledge of the flipped methodology for the course and choices were not based on any preconceived prejudices. The instructors imposed a constraint that there must be a similar quantity of participants for both groups. Each group had an identical instruction methodology in two different environments due to COVID-19: F2F flipped instruction methodology and F2S flipped instruction methodology, correspondingly. There were some PSTs who did not participate actively, which indicated the final response rate was 68 PSTs (97.14%) for F2F group and 64 PSTs (90.14%) for F2S group. The final participation rate was 132 PSTs (93.62%) for both groups, which was representative of the entire course. As displayed in **Table 1**, descriptive demographic information of PSTs showed a total participant number, gender distribution, average age, pre-test grade point average (GPA) that the average grade student had before starting the course, and educational background with social sciences, sciences, technology, arts, and others. Particularly, their average age was 20.1 and 21.0, respectively, with the total average age being 20.55 years old. In the case of gender distribution, it was a different pattern for each group. The pre-test GPA was 6.93 and 6.91 in the 0–10 scale, respectively. Finally, regarding the PSTs' educational background, both groups had a similar percentage, such as 68.3 and 65%, which showed the majority of PSTs did not have a strong STEM background from their previous education.

Instructional Design

This study was conducted in a general STEM course across two different years. The STEM course is called "Teaching of Matter and Energy" and is taught to the PSTs as a mandatory subject. The course consists of 3 h per week on theoretical contents and 1 h per week for laboratorial contents. Particularly, in the theoretical classes, all students attend simultaneously, in the same classroom for the F2F or remotely from their homes for the F2S group. In experimental contents, the class is divided into three groups, which allows for the provision of better instruction for the laboratorial activities. Together with the theoretical and laboratory class hours, the PSTs can arrange an individualized tutorial period with the instructors to clarify contents. In both F2F and F2S courses, the same syllabus was followed, and the course had the same structure. As is shown in **Table 2**, the course structure consists of five units including overall features and views of the matter and the energy. In this methodology in two different environments, an active and participatory atmosphere was promoted for their learning.

In both F2F and F2S courses, the flipped paradigm was presented from the beginning of the course and all PSTs had access to the virtual interface of Moodle that contains the course flowchart with all the principal dates and subject activities scheduled. In both cases, the flipped material consisted of pre-recorded video-lessons and lab demonstrations and texts that PSTs received, based on the syllabus, 1 week before working on them synchronously (F2F and F2S). So, PSTs can prepare for the class while watching the flipped materials. Here, they can retrieve all of the material for the whole course. Particularly, PSTs also had access to an online quiz based on a multiple-choice format that examined the subject contents. Then, they can give feedback to the instructors before the actual class, which can be considered as a "just-in-time" lecture if necessary. In this active class environment, PSTs can use in-class time to engage more with the class activities than just passively participating in the class. **Figure 1** displays a class session structure for F2F and F2S flipped instruction methodology, which incorporates a schematic vision of two groups' learning processes.

TABLE 2 | The general information of the subject implemented into the course for F2F and F2S flipped classroom.

Chapter	Title	Description
1	Science teaching/learning in primary education	19 h: This chapter consists of scientific literacy, primary science education, teaching models, strategies, techniques, and resources to instruct science in primary education.
2	The Universe	33.5 h: This chapter consists of the Universe's origin and evolution, the fundamental structure of the Universe, the solar system, the Sun, the Earth, the Moon, and the model of Sun-Earth-Moon for primary education.
3	Matter	32 h: This chapter consists of matter's physical and chemical properties with its interactions, atomic models, substances/mixtures, density, and mechanics/fluid mechanics.
4	Matter transformation	33.5 h: This chapter consists of physical changes, thermodynamics, chemical changes/reactions, and nuclear changes/reactions.
5	Energy	32 h: This chapter consists of energy types, energy transformation/transfer, conservation and degradation, energy use, light/sound, electric energy (circuits/magnetism), and energy, society, and environment.
	Total	150 h

Comparison of Students' Emotions and Perceptions Toward F2F and F2S

The comparison study between the same instruction methodology in two different environments was realized by a questionnaire survey that PSTs completed at the end of the course. The questionnaire was formed on the basis of previously published research by Roach (2014) and then was adapted to the current work after considering the course syllabus and contents. Thus, an expert panel of professors and researchers working in this topic along with the university bioethics board validated the questionnaire before collecting the information.

The designed questionnaire consisted of three different sections. The first section (section 1 Introduction) was for gathering PSTs' demographic information such as age, gender, current GPA, and educational background (see **Table 1**). The second one (section Materials and Methods) was for collecting the data of PSTs' emotions when F2F and F2S flipped

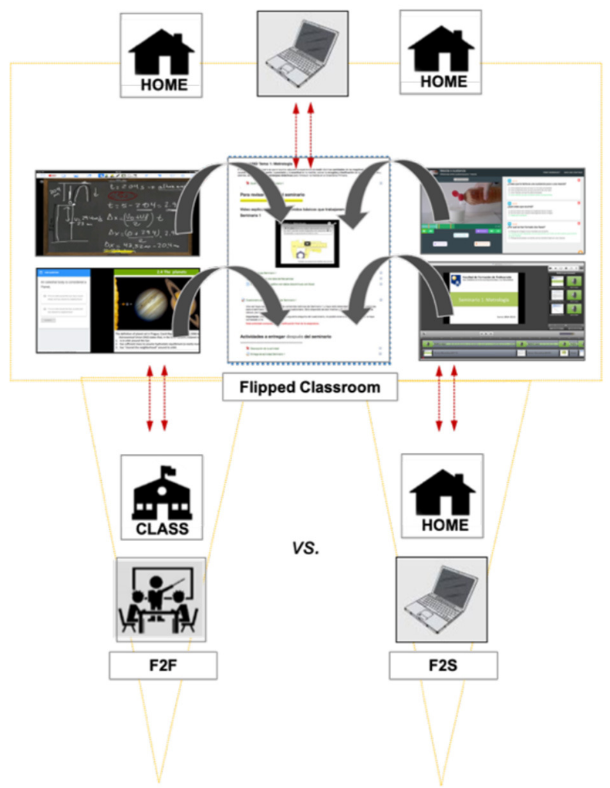

FIGURE 1 | A conceptual framework of a STEM course to examine performance and affective domain between F2F and F2S flipped classroom.

instructional methodology were followed. Here, emotions were divided into two groups, positive and negative emotions (Bisquerra, 2005). Fun, confidence, enthusiasm, and tranquility were used for the positive emotions and nervousness, concern, boredom, and fear were used for the negative emotions (Dunbar et al., 2016). PSTs answered their opinions based on the 0–10 scale about their emotions assessed toward the course, with the lowest incidence indicating 0 and the highest incidence indicating 10.

As shown in **Table 3**, the third section (section Results and Discussion) was dedicated to collecting the data of PSTs' perceptions when F2F and F2S flipped instructional methodology was followed. Here, the questionnaire consisted of nine questions that were closed type and could be defined and arranged in two groups. The first group consisted of six questions Q1 to Q6, which inquired about flipped video and other activity materials' suitability and how these flipped materials were valuable to achieving the learning and proficiencies of course goals. The second group consisted of three questions Q7 to Q9, which inquired about the entire flipped classroom and the valuable studying experience of the course (Roach, 2014; González-Gómez et al., 2019). Also, PSTs answered their opinions based on 1–5 as a five-point Likert-type scale about their perceptions assessed toward the course, which ranged from strongly disagreed (SD), disagreed (D), neutral (N), agreed (A), and strongly agreed (SA).

TABLE 3 | Five-points Likert-type survey used in this study to compare the F2F and F2S in terms of PST's perception change (Section Results and discussion).

Group of questions	Question	Description
1	Q1	I would take another course that used the same scheme as the one followed in this study.
	Q2	The video lectures helped me to learn.
	Q3	Watching the video lectures and revising the provided materials before the class sessions helped me to complete the in-class activities in a more confident manner.
	Q4	Watching the video lectures and revising the provided materials before the lab sessions helped me to easily complete the proposed activities.
	Q5	The completion of multiple-choice on-line quizzes after watching the delivered video lectures allowed me to point out the most complex contents before the class, and therefore focus on overcoming them.
	Q6	Discussing with classmates and other collaborative activities helped me to learn.
2	Q7	The course as a whole was a valuable learning experience.
	Q8	The course was more interactive when compared with others.
	Q9	The instruction methodology used in this course will be useful to apply in other subjects.

TABLE 4 | Cronbach Alpha test in this study for the questionnaire Sections Materials and Methods and Results and Discussion.

Variables	Questions	Cronbach Alpha value
Emotion (Section Materials and Methods)	8	0.89
Perception (Section Results and Discussion)	9	0.93

Statistical Analysis

The gathered data throughout the instruments implemented were analyzed in a quantitative manner. Firstly, a descriptive analysis was used to represent the sample data conclusions as the most suitable method to describe, characterize, and draw (Etxeberria and Tejedor, 2005; Jeong et al., 2019). Then, a Cronbach alpha test was used to check the reliability of questionnaires (Pintrich and De Groot, 1990; Biggs et al., 2001; Ahlfeldt et al., 2005). **Table 4** shows the value of Cronbach Alpha test for the two divisions, emotion and perception, and indicates emotion's question validity was 0.89 and the perceptions' question validity was 0.93. Consequently, for both questionnaire sections, the Cronbach alpha test can be determined as acceptable as it is close to reliable when making an important decision (Biggs et al., 2001).

The Kolmogorov–Smirnov test for normality was used to check whether data collected were normally distributed or not. Here, the data gathered were normally distributed, so we

TABLE 5 | Performance comparison between F2F and F2S.

Teaching method	Number of PSTs enrolled	Number of PSTs participating in the study	Pass rate of 1st attempt of PSTs	Pass rate of 2nd attempt of PSTs	Pass rate percentage
F2F	70	68	31	47 (31 + 16)	67.1%
F2S	71	64	33	51 (33 + 18)	70.3%

conducted a parametric statistical test. To find a significant difference and relationship between data of F2F and F2S, *t*-test as a parametric statistical analysis was performed at 95% confidence level. Both emotion and perception data were examined by score mean values that were compared and showed the significant differences' presence by means of *t* test at 95% confidence level. Then, the effect size (ES) estimation was executed in accordance with the Rosenthal method (Rosenthal, 1991). According to Cohen (1988), the ES was applied to gauge the treatment effect extent. Finally, principal component analysis (PCA) was used to deduce whether all data gathered had an objective to conduct. As a useful tool, the PCA can summarize large quantities of data. Also, it can conclude how samples collected are different from each other (F2F and F2S data), how variables can serve more significantly to the variance, and how variables can correlate with each other (Peres-Neto et al., 2005; González-Gómez et al., 2019). Finally, SPSS statistics 22.0 software was used to find out all information.

RESULTS AND DISCUSSIONS

Through the different environments with an identical flipped methodology, the results obtained showed various examinations together with performance, emotion, and perception comparison. Particularly and firstly, sample homogeneity and performance comparison were checked to complete the comparative manner of this work. Then, the comparison of emotion and perception analysis was accomplished to figure out a keener vision of PSTs' affective domain. Consequently, the results showed the principal patterns and outlines for directing performance and affective domain analysis of a STEM course during COVID-19 with a comparison study between F2F and F2S flipped classroom.

Sample Homogeneity and Performance Comparison

Table 1 describes the interesting aspect of a sample that nearly three-fourths of PSTs during the mid- and high-school stage did not take science subjects. Particularly, 20.1% of the F2F group and 15.1% of the F2S group did take science subjects during mid- and high-school stage. So, a high percentage of PSTs already lacked an understanding of the fundamental science concepts that would create many difficulties in understanding the subject. In order to finish the comparative study, the sample homogeneity if normally distributed or not was proven with reference to F2F's and F2S's emotions and perceptions. Here, the significant differences were detected between them.

In accordance with the university's statistical data stipulated during the previous 10 years, PSTs with a science background or not always had complications to finish the subject compared with the entire degree program. In reality, many PSTs took 2.5 years on average to finish this subject. Furthermore, there was an even smaller number of PSTs who took more than 4 years to finish this subject satisfactorily. Here, the performance results to gauge the proposed methodology success were compared between F2F and F2S groups. **Table 5** summarized the results gotten for F2F and F2S teaching methodology. The final grade for each group shows 7.54 (F2F) and 7.23 (F2S), respectively. For flipped instruction methodology of F2F and F2S, even though the final pass rate of PSTs increased enough (67.1 and 70.3%), around 30% of students still needed to take the course again. Finally, the information about the pass rate in the two attempts that the university provided is also summarized in **Table 5**. Although for both groups, the pass rate were similar, higher scores were observed for the F2S groups, although no significant differences were established.

Course Emotions Comparison

Figure 2 summarized the PSTs' comparison of emotions toward the flipped instruction methodology following F2F and F2S after finalizing the course. All scores of positive and negative emotions based on the statistical comparison analysis were significantly different in both F2F and F2S instructional settings. The mean score values for positive emotions for the F2F group was 27.6 (std dev = 4.24), whereas the mean score value for the F2S group was 14.7 (std dev = 8.71). The *t*-test showed that the difference between these mean values were significant ($p < 0.001$, $d = 1.91$), suggesting a very large effect. On the other hand, the score values for the negative emotions for the F2F group was 15.7 (std dev = 9.17), while the mean score value for the F2S group was 29.0 (std dev = 7.19). Again, the *t*-test showed that the difference between the mean values of both groups were significant ($p < 0.001$, $d =$ 1.44), which corresponded with a very large effect.

To assess the difference among emotions, each one of the assessed emotions were analyzed. The main results are summarized in **Figure 3**. Thus, with respect to the positive emotions, the F2F group showed high scores that had an average 3.1 points difference of the points specified by the F2S PSTs. Particularly, the positive tranquility emotion had a notable score, which had more difference among the positive emotions (6.53 in F2F and 2.92 in F2S course). On the contrary, F2S had a high score of negative emotions, with the negative concern emotion indicating more difference among the negative emotions (4.90 in F2F and 8.53 in F2S course). Also, the negative fear emotion along with negative concern emotion pointed out a

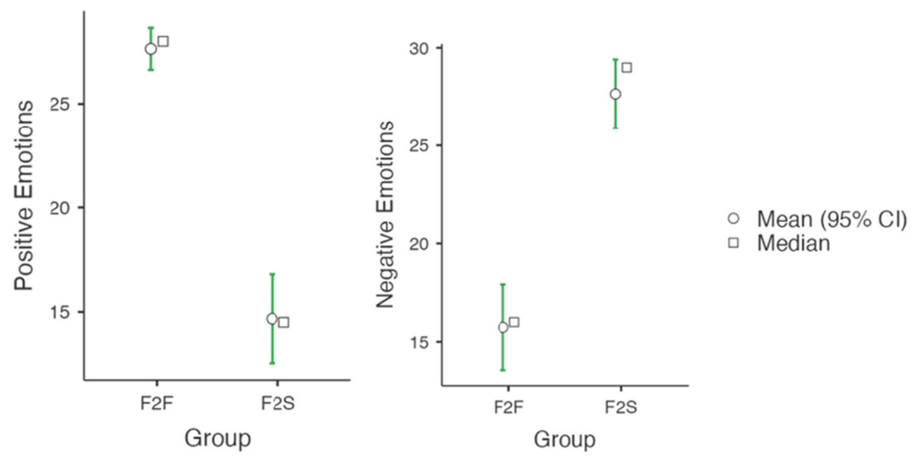

FIGURE 2 | Emotion analysis for F2F and F2S flipped classroom after the course completion.

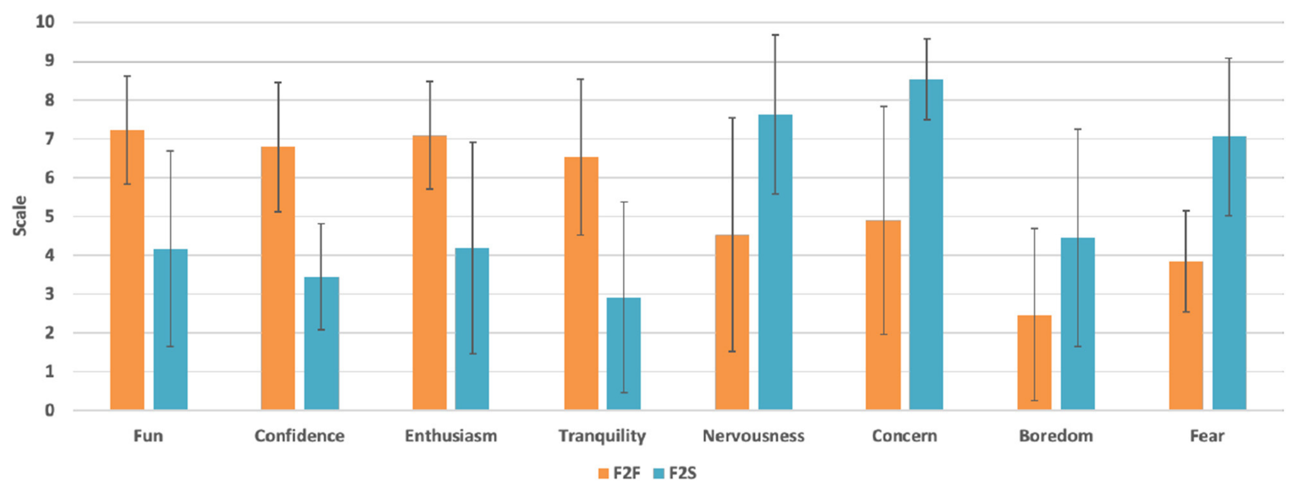

FIGURE 3 | Single item assessment of the emotions for F2F and F2S flipped classroom after the course completion.

TABLE 6 | Emotion comparison between F2F and F2S flipped instruction methodology.

Method	Fun	Confidence	Enthusiasm	Tranquility	Nervousness	Concern	Boredom	Fear
F2F (SD)	7.23 (1.40)	6.79 (1.66)	7.09 (1.39)	6.53 (2.01)	4.53 (3.00)	4.9 (2.93)	2.47 (2.22)	3.84 (1.30)
F2S (SD)	4.17 (2.51)	3.45 (1.36)	4.19 (2.72)	2.92 (2.46)	7.63 (2.05)	8.53 (1.04)	4.45 (2.79)	7.05 (2.03)
p-values	0	0	0	0	0	0	0	0
ES (*d*)	1.52	1.65	1.34	1.61	1.13	1.54	0.78	0.97
	Very large	Very large	Very large	Very large	Large	Very large	Medium	Large

All the assessed emotions were statistically different (parametric t-test at 0.05 significance level). The ES means of Rosenthal approach for the significant different variables.

big difference between F2F and F2S groups (3.84 and 7.05, respectively). The negative boredom emotion in both groups showed the lowest value, which was 3–4 points less than other negative emotions recognized.

Table 6 described the PSTs' comparison of emotions toward the flipped instruction methodology following F2F and F2S after finalizing the course. There are some scores of positive and negative emotions based on the statistical comparison analysis

TABLE 7 | Perception comparison between F2F and F2S flipped instruction methodology of the Likert-type test.

Method	Group 1						Group 2		
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
F2F (SD)	4.50 (0.76)	4.52 (0.61)	4.47 (0.72)	4.37 (0.73)	4.43 (0.82)	4.50 (0.72)	4.28 (0.84)	4.47 (0.70)	4.50 (0.70)
F2S (SD)	3.89 (0.88)	4.09 (0.85)	4.33 (0.76)	4.28 (0.75)	3.41 (0.97)	3.58 (0.97)	3.03 (1.07)	2.56 (1.10)	2.75 (1.02)
p-values	0.000	0.000	No Sig.	No Sig.	0.000	0.000	0.000	0.000	0.000
ES (*d*)	0.69	0.51	0.17	0.10	1.08	1.01	1.25	2.03	1.93
	Medium	Medium	–	–	Large	Large	Very large	Huge	Very large

All the assessed perception questionaries were statistically different (parametric t-test at 0.05 significance level). The ES means of Rosenthal approach for the significant different variables.

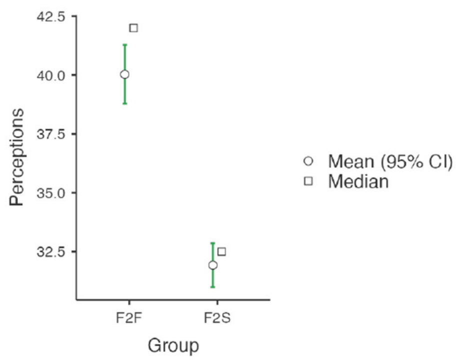

FIGURE 4 | Perception analysis of F2F and F2S flipped classroom after the course completion.

that were significantly different in both F2F and F2S instructional settings. Thus, the ES analysis specified that the instruction methodology had a medium to large effect in the whole emotion measured as indicated in the table (Cohen, 1988). Particularly, positive emotions' ES was all very large effects of significant different variables and negative emotions' ES was situated from medium to very large effect of significant different variables. Here, we have used the Cohen's d to find out the significant difference for each variable between two means divided by a standard deviation for the data as shown in Equation (1). The value of d's magnitude indicates the ES size: very small is between 0 and 0.01, small is between 0.02 and 0.20, medium is between 0.21 and 0.50, large is between 0.51 and 0.80, very large is between 0.81 and 1.20, and huge is between 1.21 and 2.00.

$$s = \sqrt{\frac{(n_1 - 1)\, s_1^2 + (n_2 - 1) s_2^2}{n_1 + n_2 - 2}} \qquad (1)$$

Course Perceptions Comparison

Table 7 represented the PSTs' comparison of perceptions toward the flipped instruction methodology following F2F and F2S after finalizing the course. The main values of each questionnaire can be found in this table. Moreover, to catch a closer observation of PSTs' perceptions for both F2F and F2S instruction methodologies, **Figure 4** summarizes the responses collected for the perception questionnaire part. The mean score values students' perception for F2F group was 40.0 (std dev = 5.26), whereas the mean score value for F2S group was 31.9 (std dev = 3.79). The t-test showed that the difference between these mean values were significant ($p < 0.001$, $d = 1.76$), suggesting a very large effect.

Again, to have a detailed view of the perceptions, each item was also analyzed. According to the statistical comparison, **Table 7** showed that some perception scores are significantly different in both F2F and F2S instructional environments. However, Q3 and Q4 questionnaires' scores indicated that there were significant differences in statistical assessment by both F2F and F2S groups. The rest of the questions for perception scores provided were significantly different in both F2F and F2S instructional environments. In addition, the ES analysis indicated that the instruction methodology had a small (no ES) to huge ES in the perception assessed as indicated in the table (Cohen, 1988). Particularly, Q1–Q6 perception items were located in between small (no ES) to large variables and the Q7–Q9 perception items were located in between very large to huge variables. Here, we used the same manner of Cohen's d to find out their significant difference for each variable between two means divided by a standard deviation for the data aforementioned.

Figure 5 showed the PSTs' perception part of the questionnaire with a closer view for both F2F and F2S instruction methodologies provided. According to the statistical comparison analysis, all perception questionnaires provided were significantly different in both instructional environments. Particularly, Q1, Q2, Q5, and Q6 items had around a 0.5 increase between F2F and F2S while Q3 and Q4 items had 0.14 and 0.19 difference, respectively, in the Group 1 questionnaires. In the Group 2 questionnaires, Q7–Q9 had more than 1 point and even close to 2 points difference between F2F and F2S groups after the course completion. Specifically, the Q8 item described PSTs' perceptions about the course learning experience as a whole. In this item, the average score of F2F was 4.47 points while the F2S showed 2.56 points. So, the F2F offered a higher positive perception about the learning procedure for the identical contents and could be considered as a significant contribution in PSTs' learning involvement and practice. Thus, both F2F and F2S groups agreed or strongly agreed the practicality of video lectures and other flipped materials before class improved learning target attainment and allowed PSTs to achieve the in-class works more confidently and easily. Particularly, those

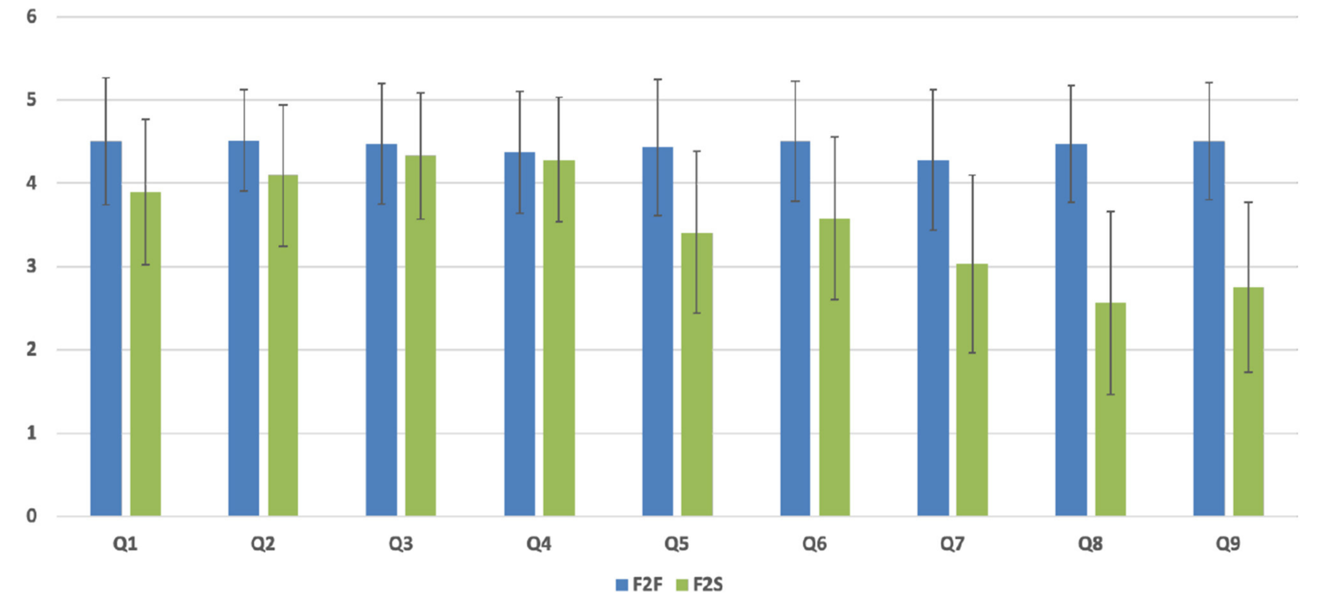

FIGURE 5 | Single item assessment of the perceptions of F2F and F2S flipped classroom after the course completion.

PSTs enrolled in the F2F course agreed or strongly agreed to have more flipped and presential course as the teaching methodology as a whole, which assisted in realizing their learning purposes.

PCA Test

Figure 6 showed the PCA analysis in order to get a clear image of the instruction methodology's effect over the PSTs' emotion and perception toward STEM between F2F and F2S flipped instruction methodology. Here, it indicated a PCA loadings diagram about emotion and perception, in which the X and Y axes showed principal component 1 and principal component 2, that explained 52.3 and 23.1% of the total variance, respectively. According to the PCA results, the first PC was able to group the sample in to two groups (F2F and F2S answers). Precisely, prediction ellipses were also added to the PCA scores plot to show the probability that a new observation from the same group (F2F or F2S) will fall inside the ellipse with a 95% probability. Thus, F2F answers were located mainly in the positive axis of PC1, while F2S answers were grouped in the negative part of PC1. When comparing the score and loading plots, it is clear that PC1 represented the effect of the instruction methodology in the emotion toward science of PSTs, and it was able to distinguish between F2F and F2S groups. F2F scores were in the positive axis of PC1 which corresponds with positive emotion, while the F2S scores were in the negative axis of PC1 that corresponds with the negative emotions. Regarding the loadings corresponding to the students' perception, they are also located in the positive axis of PC1, and therefore are more correlated with the F2F scores.

Discussion

The obtained outcomes show the information that can be considered as a novel approach to examine PSTs performance and affective domains of F2F and F2S flipped instruction methodology during the COVID-19 pandemic. This research stipulates an exclusive comparison for a specific flipped STEM education of PSTs and can fill a niche/gap of different environments with an identical methodology to measure performance and affective domains.

Although on-line and virtual learning showed a consistent growing tendency, many institutes were not prepared for a significant transition due to the COVID-19 pandemic (UNESCO, 2020; WHO, 2020a,b). Many researchers confirmed that on-line and virtual learning along with the ICTs could be considered as a proper educational model in a teaching-learning process of STEM course (Lee and Lee, 2008; Pereira et al., 2008; Shee and Wang, 2008). Here, among teacher to teacher, teacher to student, and student to student interactions, ICTs can act as a scaffolding for communications (Garrison, 2000; Lee and Lee, 2008; Lozano et al., 2013). Thus, the technological integration to STEM education could fill a current educational niche, although there are existing many challenges, which will be integrated to transformational STEM teaching-learning (Eneroth, 2000; Paechter et al., 2010; Nowotny et al., 2018). On the other hand, these innovative systems proposed could be of great help for STEM education development in long-term teaching-learning (Garrison, 2000; Azeiteiro et al., 2014). However, general on-line and virtual learning systems are still required to examine more specific models' efficiency in-depth such as higher STEM education through e-learning systems (McVey, 2016; Nowotny et al., 2018). Therefore, a proper methodology and system proposed could achieve its objectives adapting to STEM education while complying with COVID-19 guidelines.

Together with the confirmation aforementioned, the flipped classroom methodology along with digital materials in STEM

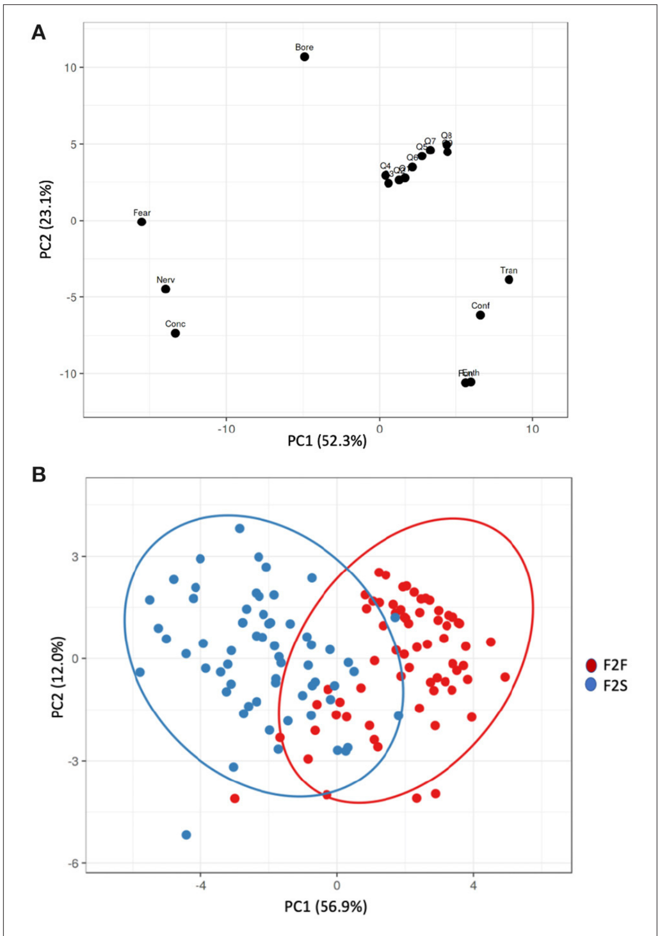

FIGURE 6 | The PCA diagram: **(A)** loading corresponding to the questionnaires of emotion and perception; **(B)** scores plots corresponding to the PSTs distribution of F2F and F2S flipped classroom.

can provide a more suitable teaching-learning environment to reach significant and fruitful achievements, while complying with the WHO social distancing suggestions during the COVID-19 pandemic (Blair et al., 2016; Cao et al., 2020; WHO, 2020a). Previous studies also found that video-lectures supported shaping conceptual understanding and was valuable the convenience of students (Imran, 2013; Roach, 2014; Long et al., 2016). The performance can be improved in the context of students' learning due to having more in-class time along with active learning integration and consequence (Akçayir and Akçayir, 2018). Pintrich and De Groot (1990) indicated that positive emotions were vital for promoting significant learning in the STEM course along with the theories of emotions and learnings analyzed and investigated by previous researchers (Bower, 1981; Schwarz, 1990; Abele, 1995; Hascher and Edlinger, 2009). Here, students' perception can be analyzed for their opinions of flipped classroom methodology (Blair et al., 2016; Akçayir and Akçayir, 2018). Kemp and Grieve (2014) also concluded that, although same academic performance was achieved in an F2F and F2S environment, students do prefer to accomplish specific activities in F2F settings. Thus, in the context of affective domain, Marshall (2011) indicated a significant relationship of students' learning favoring to F2F along with previous research in F2F and F2S setting (Baker, 2012; Blair et al., 2016; Jeong et al., 2019). Hence, based on the previous literature and reasons confirmed, a proper methodology and system proposed could achieve its objectives with the comparison of face-to-face (F2F) and face-to-screen (F2S) flipped methodology. Thus, it can overcome the COVID-19 situation in terms of the students' performance and affective domains.

Consequently, although the transition from the F2F to F2S classes could be considered as a positive process in institutes, the instructors and students confronted struggles and difficulties in the platform use for on-line and virtual classes. Along with these problems, the performance and affective domain results obtained by the PSTs specified the direction to follow; there were crucial considerations that future teachers were required to reflect on their on-line and virtual classes along with improvements from these instructions to better equip themselves for future classes. Particular attention was required in students' emotions during on-line and virtual class when instructors engaged. Also, specific comparison results obtained with the methodologies and objectives in the PSTs performance and affective domain of flipped STEM education could be reapplied to various educational areas and contexts when there were available data required due to its flexible characteristics.

CONCLUSIONS

The research shows an examination of two different situations' comparison of an identical flipped instruction methodology, F2F and F2S, in terms of students' performance, emotion, and perception in a STEM course before and after the COVID-19 pandemic. It was designed and considered as a randomization examination with 132 PSTs, 68 and 64 PSTs, for the primary education bachelor's degree in Spain. Here, various statistical analyses were applied to data and questionnaires proposed.

According to the results obtained in this study, both groups of PSTs' increased their grade without significant difference after the course completion. The F2F had a significant effect on PSTs' perception and emotion toward the course and created classes that were more interactive. Particularly, in the comparison of students' emotions toward the instruction methodology, the ES analysis indicated that positive emotions' ES was all very large for significant different variables and negative emotions' ES was situated from medium to very large for significant different variables for both F2F and F2S after completing the course. Then, in the comparison of students' perceptions toward the instruction methodology, section 3 of the questionnaire (items Q7 to Q9) indicated a significant difference as ES showed a very large to huge index after the course was completed for both groups of F2F and F2S. Finally, the PCA test described that F2F answers were located mainly in the positive emotion part of PC1, while F2S answers were grouped in the negative axis of PC1. The scores plots indicated that positive emotions and perceptions were located in the positive axis of PC1 while negative emotions were grouped in the negative axis of PC1.

Consequently, although the conversion from F2F–F2S in the higher education was a fruitful procedure, students and instructors confronted difficulties in the use of online classes through a platform. In this research, the comparison demonstrated how to reflect the challenges and drawbacks meaningfully by the results obtained, especially emotions in the F2S group. Here, they emphasized emotions as the crucial criteria that instructors needed to consider when teaching virtual and online classes and taking advantage of these findings to better equip themselves for future classes. Although the F2F flipped classroom has enough virtual and online content, for the F2S classroom, more appropriate adoption and transition is required to promote both performance and affective domains of PSTs. Thus, it will allow PSTs to be more interactive in virtual and online context for their future implementation with active instruction methodology to educate future students to teach STEM contents. Finally, the main limitations of this study could be found in the sample size and the lack of analysis of other variables that might influence the results, such as participants' gender.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by La Comisión de Bioética y Bioseguridad de la Universidad de Extremadura, Spain. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

This work was funded through the Research Projects IB18004 and GR18004 by Consejería de Economía, Ciencia y Agenda Digital de la Junta de Extremadura (Spain) and FEDER funds.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Consejerería de Economía e Infraestructura de la Junta de Extremadura y FEDER funds (Projects IB18004), whose support made this research possible.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers in Psychology

ORIGINAL RESEARCH
published: 24 August 2021
doi: 10.3389/fpsyg.2021.661631

A Study of Disposition, Engagement, Efficacy, and Vitality of Teachers in Designing Science, Technology, Engineering, and Mathematics Education

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OPEN ACCESS

Edited by:
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Reviewed by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: 31 January 2021
Accepted: 15 July 2021
Published: 24 August 2021

Citation:
Lin P-Y, Chai CS and Jong MS-Y (2021) A Study of Disposition, Engagement, Efficacy, and Vitality of Teachers in Designing Science, Technology, Engineering, and Mathematics Education. Front. Psychol. 12:661631. doi: 10.3389/fpsyg.2021.661631

This study proposes and tests a theoretical model of how perceptions of disposition, engagement, and efficacy of teachers for science, technology, engineering, and mathematics (STEM) e-learning can predict their sense of vitality when they designed STEM education. Upon the proposition, we developed and validated an instrument for examining the relationships between these variables. The participants were 122 secondary teachers of STEM education from Hong Kong. The instrument included four design aspects as follows: (i) disposition, (ii) lesson design engagement, (iii) efficacy for designing STEM e-learning, and (iv) vitality of teachers after attending a series of STEM professional development activities. To analyze the relationships among the variables, partial least squares structural equation modeling was employed. The disposition of teachers predicted lesson design engagement and both of these factors, in turn, predicted efficacy for designing STEM e-learning. In other words, if teachers have a high proposition toward designing learning activities, their engagement in the lesson design process may enhance their capacities in designing and implementing such activities. Also, the disposition of teachers and lesson design engagement predicted their vitality, revealing that well-suited STEM teachers should not only be able to design a STEM curriculum but also have a positive perception of STEM education.

Keywords: stem education, vitality, partial least squares structural equation modeling, lesson design engagement, disposition, efficacy

INTRODUCTION

With the rapid development of science and technology, the urgent need for science, technology, engineering, and mathematics (STEM) professionals has placed new demands for the educational systems worldwide (Huang and Jong, 2020). Integrative STEM education has received increasing attention in the field of education. An Organisation for Economic Co-operation and Development (OECD) report showed that STEM competencies are required not only for the nascent STEM workforce but also for solving real-world problems in daily life (OECD., 2016). Integrated STEM education has also been advocated to promote skills and competencies of 21st century among students, including inquiry skills, problem-solving, critical thinking, creativity, and innovation, as well as to develop a STEM-literate citizenry (Partnership for 21st Century Skills, 2011; English and Gainsburg, 2016). Advancing STEM competencies of students has thus become a crucial issue. This, in turn, demands that teachers develop interdisciplinary competencies in designing and facilitating STEM lessons (Lau et al., 2020).

With the proliferation of STEM education, an emerging research trend has investigated the development of K-12 teaching and teacher education in STEM education (Li et al., 2020). Researchers and educators have responded to this ongoing call to advance integrative STEM teaching and learning (English, 2016). Pedagogically, STEM education is not merely a combination of the four disciplines of STEM. Instead, current STEM lessons usually present design challenges, situations, and tasks that require students to use knowledge and skills to solve real-world problems from multidisciplinary perspectives (Feinstein and Kirchgasler, 2015; Chai et al., 2020). However, conventionally, these four disciplines have been taught in isolation. To promote changes in STEM curricula and instruction, the core content and interdisciplinary activities of STEM subjects must be connected (Henderson et al., 2011). Competency of teachers in designing an integrated STEM curriculum is crucial to develop interconnected STEM knowledge of students and to encourage students to pursue STEM-related careers (English, 2017; Timms et al., 2018). East Asian countries and regions, including Hong Kong, constantly ranked among the top 10 countries worldwide in international assessments of science and mathematics (OECD., 2016; Mullis et al., 2019). Nonetheless, in order to promote integrated understanding and improve the creativity and problem-solving ability of students, Hong Kong has launched an integrative STEM pedagogical framework (Education Bureau, 2016; Chen and Lo, 2019; Leung, 2020). The newly established curriculum framework will only be fruitful if teachers are willing to be engaged in the continuous effort needed for the design and refinement of STEM curricula (Chai et al., 2020).

To date, there are relatively few STEM studies that have been conducted in Asian contexts (Li et al., 2019). One recent study among K-12 school teachers in Hong Kong has indicated that few participants (<6%) regarded themselves as "well-prepared" for STEM education (Geng et al., 2019). Previous studies have indicated that the disposition of teachers and their lesson design practices were predictive of their efficacy in designing technology integrated lessons (Koh et al., 2015). This study explores the relationships among disposition, lesson design engagement, and lesson design efficacy of teachers, along with the vitality of teachers (in the literature review). It is based on the premise that teaching entails the design and redesign process (Kali et al., 2011; Hong et al., 2019). Current research highlights the need for teachers to be engaged in lesson design work, especially in literature that adopts the technological pedagogical content knowledge (TPACK) framework. While lesson design is generally recognized treated as demanding work (McKenney et al., 2015), the rejuvenating effects of design work among teachers have apparently been overlooked. Successful design can help teachers gain a sense that they could overcome challenges put forth by current reforms [e.g., information and communications technology (ICT) integration and interdisciplinary STEM]. In this study, the effects are epitomized as vitality. In other words, this study aims to first test a survey for its psychometric properties to measure the proposed factors, and subsequently test if the factors associated with design work could contribute to the sense of the vitality of teachers. The findings may point out to an expansion of understanding about the effects of design work and the importance of facilitating the design work of teachers during their professional development. This study could help researchers to further understand the psychological factors at play when teachers undertake the endeavor of designing STEM curricula.

LITERATURE REVIEW

Design and Design of Teachers

Scholars across different disciplines have developed a nuanced understanding of design (i.e., design knowledge and design pedagogy) and recognize that design thinking helps people explore and understand the complex nature of the design (Cross, 2001; Brown, 2008). Although the design is defined in multiple ways, it is generally a cognitive and physical process in which people respond to situations in need of solutions or situations that people desire to change. One of the accepted definitions referred design to as iterative processes in which the designers formulate understanding through initial problem representation which points to a tentative solution, and these initial representation and solution then "talk back" to the designers to stimulate further reflective understanding about the situation. Subsequently, the solution may be refined or new solutions may be formulated (Schön, 1983; Lawson, 1997; Koh et al., 2015). Several rounds of iteration may occur until an acceptable solution is chosen. Through the iterative design circles, an optimal concept is gradually formed in knowledge generation and integration activities, which is called the design thinking process. Design thinking is not only a problem-solving process; it is treated as a way of thinking that becomes a habit of mind (Cross, 2011).

Design problems are generally accepted as ill-structured problems that do not have clear problem-solving paths (Jonassen, 2000). In the context of education, designing instruction is the first necessary step to engender educational reform (Henriksen et al., 2017; Wu et al., 2019). Instructional design is widely applied as a process-centric model, for example, the analyze–design–develop–implement–evaluate model (Branch, 2009). The inception of the notion of TPACK as a theoretical framework to account for the knowledge that teachers need to create through design talk for technology integration (Koh et al., 2015; McKenney et al., 2015), process-oriented instructional design has been recast in the light of design thinking with heavy emphases on contextual considerations. Designing an interdisciplinary STEM curriculum involves multiple areas of content knowledge and multiple types of technological pedagogical knowledge. Only few teachers are well-versed in all four subject areas and teachers generally lack engineering knowledge (Al Salami et al., 2017; Chai, 2019). Interdisciplinary STEM curriculum design thus requires teachers to acquire diverse sets of knowledge and to be skillful in coordinating the multiple sources of knowledge through collaborative talk. These knowledge sources have to be synthesized and transformed into implementable classroom lessons (Chai et al., 2019). The lesson design processes are likely to be discursive, and the outcomes are uncertain. While some teachers might have a positive attitude to embrace such processes, and some teachers might resist (Le Fevre, 2014). Regardless of the disposition of teachers toward design, it seems clear that the engagement of teachers in design activities is the necessary means for them to develop the needed competencies (Lawson, 2005; Dorst, 2008).

Successful implementation of STEM curriculum depends on the attitudes of teachers toward the undertaking of the necessitated design work (i.e., disposition toward design) (Kerr, 1981; Bell, 2016; Al Salami et al., 2017). The positive attitude of teachers toward designing instruction beyond their disciplines determines their engagement in the instructional design process (i.e., lesson design engagement) (Chai and Koh, 2017) and their efficacy to integrate relevant engineering and technological concepts into science and mathematics curriculum (i.e., efficacy for designing STEM learning) (Chai et al., 2020). Chai et al. (2020) have indicated that designing technology-enhanced instruction for a single subject alone is a challenging task. Developing interdisciplinary lessons with technologies possesses a higher level of challenge. The ability of teachers to overcome the challenges in designing and integrating the subject matters contributes to their competencies. Based on the self-determination theory (Ryan and Deci, 2020), enhanced competencies contribute to the overall sense of personal well-being. This study chooses the notion of vitality, which denotes the overall motivation and well-being a person experienced (Blackwell et al., 2020), as one of the possible dependencies of the variables discussed regarding teachers in the design processes of STEM education. The aim of this study, which recruited 122 Hong Kong secondary teachers, was to investigate the interrelationships of perceptions of teachers of disposition, lesson design engagement, efficacy for designing STEM e-learning, and vitality after they had attended a series of STEM professional development activities.

Science, Technology, Engineering, and Mathematics Education

The conventional method of learning STEM is as a collection of individual subjects, which neglects the connections between these disciplines (Bybee, 2013; Leung, 2020). STEM in education refers to both a curriculum and pedagogy. Teachers can design cross-curricular authentic problems in meaningful and relevant contexts for students to engage in such STEM learning (Hallström and Schönborn, 2019; Margot and Kettler, 2019). Essentially, STEM education should involve curriculum activities that require students to apply science and mathematics knowledge and incorporate technologies to accomplish real-world problem-solving through design. For example, students may apply STEM content knowledge and skills to construct a prototype in engineering design (Brophy et al., 2008; Fan and Yu, 2017). Therefore, STEM education focuses on preparing students with the design and design-thinking competencies required to connect scientific inquiry, mathematical thinking, technological literacy, and engineering design to solve relevant, authentic problems (Fan and Yu, 2017; Li et al., 2019). In summary, STEM learning must be relevant and authentic, and it must require students to engage in a problem-solving process. Teachers should design real-world situations that allow students to transfer knowledge and skills between STEM subjects to optimize their designs for problems. Teachers are expected to possess the capacities to design effective interdisciplinary teaching.

However, most teachers have received conventional training that focuses on teaching knowledge and skills and pays limited attention to designing meaningful and authentic learning situations (Wu et al., 2019). Design is generally classified as ill-structured problem-solving, and teachers lack experience in designing and implementing integrative STEM learning (Dorst and Cross, 2001; Chai and Koh, 2017). To address this concern, the professional development of STEM teachers needs to be investigated along with the disposition of teachers toward design and design competencies (Al Salami et al., 2017; Margot and Kettler, 2019). The literature review that follows thus includes a section on design-associated variables in relevant STEM research.

Science, Technology, Engineering, and Mathematics Design Capacities

Science, technology, engineering, and mathematics researchers have begun to consider the design-thinking capacities of teachers (Li et al., 2019; Wu et al., 2019), but multiple challenges in designing STEM education remain to be discussed. First, teachers must develop design beliefs aimed toward student-centered, innovative instruction so that they may design appropriate curricula to map student needs, classroom activities, and instructional strategies (Yeh et al., 2015; Voogt and McKenney, 2017). Second, school curricula are most often disconnected from real-world contexts. School teachers need to prepare STEM content knowledge and skills of students, as well as their capacity to apply the knowledge and skills to authentic problems (Honey et al., 2014; Moore et al., 2014). Furthermore, many schoolteachers with separate subject specialties have limited experience in designing integrative STEM teaching or in coping with design problems spanning multiple STEM disciplines (Al Salami et al., 2017; Cavlazoglu and Stuessy, 2017). When developing and designing STEM curricula and instruction, teachers must use design-oriented approaches that encourage students to connect scientific, mathematical, engineering, and technological knowledge optimally to solve real-world problems (Bell, 2016; Falloon et al., 2020). There is an obvious need to plan for the coordination of basic and core concepts so that the interdisciplinary efforts could promote subject literacy. This is highly complex and not adequately addressed in teacher education (Chai, 2019). Therefore, researching the views of teachers on the design of STEM learning and their lesson design competencies in relevant contexts is crucial.

Disposition Toward Design

Disposition is defined as confidence in handling complexity and persistence in dealing with problematic situations (Halpern, 1998; Jong et al., 2020). Disposition toward design refers to the attitude of a teacher toward a design situation (Dong et al., 2015).

The disposition helps teachers to remain open to the new design experience and to be tolerant of the ambitious design situation. It promotes an empathetic understanding of teachers toward the needs of students (Michlewski, 2008; Cross, 2011). Related studies have indicated that the views of teachers about their disposition toward design are significant indicators in technology integration (Koh et al., 2015; Chai and Koh, 2017). Furthermore, Chai et al. (2017) revealed that the design beliefs of teachers are significant predictors of their technological pedagogical content knowledge after they have participated in lesson design activities. STEM education entails a technology-integrated process. In this study, we expanded on previous studies about the design disposition of teachers into the STEM education context, which is more complex than integrating ICT into one subject area. Thus, we proposed and investigated the hypothesis that teachers with stronger design disposition are more inclined to design and develop STEM learning.

Lesson Design Engagement

Lesson design engagement refers to a design-thinking process through which designers can identify problems, empathize with the needs of users, ideate possible solutions, prototype models using promising ideas, gather feedback, and redesign (Razzouk and Shute, 2012). When teachers act as designers, they are involved in an iterative process to design, redesign, and reflect on their practices (Laurillard, 2013). The conventional role of a teacher is to deliver information and knowledge through textbooks, lessons, and activities, with less emphasis on designing a learning environment and activities that engage students in knowledge construction (Wiggins and McTighe, 2005). The key to STEM education lies in the dynamic creation of integrative knowledge and design practice. Design-thinking is essential in the lesson design processes for teachers to develop and implement integrative STEM education through conceptualizing, ideating, designing, prototyping, and evaluating outcomes, artifacts, and solutions (Li et al., 2019).

Although studies have illustrated that a well-integrated STEM education conceptual framework and professional development can help teachers to acquire the necessary expertise and promote their confidence, attitudes, knowledge, and efficacy when designing STEM instruction (Nadelson et al., 2013; Kelley and Knowles, 2016), knowledge about how lesson design engagement of teachers is related to their STEM learning and STEM curriculum design processes remains lacking. Therefore, this study examines the lesson design engagement of teachers and how this may be associated with their efficacy for designing STEM courses. Logically, engagement would enhance efficacy.

Efficacy for Designing STEM e-Learning

Self-efficacy is defined as the perceived capacity of a person (Bandura, 2006) and belief in their ability to successfully execute a given behavior (Beck and Ajzen, 1991). Efficacy for designing STEM e-learning refers to the belief of a person about his/her ability to work effectively through specific instructional design processes (Collier, 2002; Thibaut et al., 2018). Efficacy of teachers extends beyond their perceived personal capabilities to a more general view of their preparedness for teaching and affecting the desired student learning (Ross and Bruce, 2007; Settlage et al., 2009; Kelley et al., 2020). Efficacy of teachers for designing STEM learning can thus be considered as their self-expectations that they will be able to design tasks that require students to use STEM knowledge and skills in the context of complex situations or problem-solving processes (Honey et al., 2014). However, researchers have highlighted that relationships among mathematics (Fitzallen, 2015; Gravemeijer et al., 2017), engineering (Barrett et al., 2014; English et al., 2017), and other STEM disciplines require improvement. This points out the need to enhance the design capacity of teachers to foster the connections. Engagement in professional development activities that are targeted to design STEM curriculum activities generally improves the design capacity of teachers and hence their efficacy for designing STEM e-learning.

Although STEM research is emerging in education literature, the effectiveness of integrated STEM education for teachers and students remains underexplored (Honey et al., 2014; English, 2017). Efficacy of teachers for designing STEM e-learning is likely to influence learning outcomes and quality of students in the STEM classroom (Dilekli and Tezci, 2016; Zee and Koomen, 2016). In this study, efficacy for designing STEM e-learning refers to the efficacy of teachers to design STEM activities that are mediated by information and communication technologies.

Vitality

Depending on the circumstances, a person may experience both positive (e.g., lively and energetic) and negative feelings (e.g., burnout and feeling drained) (Ryan and Frederick, 1997; Farber, 2000; Skaalvik and Skaalvik, 2010; Flook et al., 2013). Vitality refers to the feeling of energy and excitement of an individual (Ryan and Frederick, 1997). Vitality is associated with the overall motivation and well-being to adapt to challenges (Miksza et al., 2019; Blackwell et al., 2020). As a person with a higher sense of disposition toward design is more open and unintimidated by the challenges, disposition toward design may be positively associated with vitality.

Teachers with high vitality are engrossed in their roles as teachers, and they have a tendency toward viewing teaching in a positive light (Intrator and Kunzman, 2007; Jong, 2019). Vitality is also related to agency and intrinsic motivation to pursue meaningful and successful teaching through enthusiasm for their work (Ryan and Frederick, 1997; Jong, 2016). Meaningful and successful teaching is premised upon strong lesson design, which is the outcome of the lesson design engagement of teachers. In other words, when teachers possess the disposition toward design, they are willing to spend time to be engaged in designing STEM learning that leads to innovative teaching (Koh et al., 2015). This could translate to successful teaching and hence contribute to the vitality of teachers. In summary, knowledge of the subject and pedagogy is insufficient for teachers; their energy, enthusiasm, and positive attitude toward designing STEM lessons and facilitating student learning are important (Blackwell et al., 2020).

Teachers with higher vitality are sympathetic to the needs of students, more dedicated to purposefully improving learning conditions, and competent in providing teaching practices to inspire and engage their students in learning. They are also resilient in their responses to problems and challenges in the classroom (Margolis and Nagel, 2006). In particular, in the field of STEM education, teachers may encounter many design problems when developing integrative STEM learning contexts (English, 2016; Li et al., 2019). It is necessary to investigate the teaching beliefs and behaviors that may be related to the energy and inspiration of teachers to overcome these problems.

Study Aim

The aim of this study was to investigate the relationships among the disposition of teachers toward design, lesson design engagement, efficacy for designing STEM e-learning, and vitality. The disposition toward design has been introduced to assess the inclination of teachers toward a design situation. However, Lesson design engagement of teachers provides a more comprehensive view of the behaviors of teachers during the design process. The efficacy of teachers for designing STEM e-learning illustrates their expectations regarding their capability of designing a STEM e-learning context. Vitality reflects the positive feelings of teachers in terms of energy, enthusiasm, and excitement about design.

Together, this framework may provide complimentary data supporting further STEM promotions. Li et al. (2019) advocated for design and design-thinking specific to STEM teachers. Nonetheless, relatively few studies have explicitly connected these design elements with the efficacy of teachers for designing STEM courses and vitality. Thus, the research question was formulated to guide this study: How do the disposition of teachers toward design, lesson design engagement, and efficacy for designing STEM e-learning relate to vitality in the model?

METHODS

Participants

The participants in this study were 122 secondary school teachers (77.8% male) of STEM education from Hong Kong. The mean age of the teachers was 39.8 years (SD = 9.51 years), and the mean teaching experience was 15.1 years (SD = 9.1 years). All the participants had experience in STEM teaching. They participated voluntarily in this study and completed the survey after attending a series of STEM professional development activities that engaged the teachers to design STEM activities. They were ensured that their privacy would be maintained.

Instruments

The instrument measured four design aspects, namely, disposition toward design, lesson design engagement, efficacy for designing STEM e-learning, and teacher vitality (measured items are listed in **Appendix 1**). Self-reported questionnaires were used in this study. The instruments for the disposition toward design (four items, $\alpha = 0.84$; e.g., "I am comfortable with the presence of uncertainty.") and efficacy for designing STEM e-learning (five items, $\alpha = 0.91$; e.g., "I can formulate in-depth discussion topics about the STEM content knowledge for students' online discussion.") were based on the survey developed by Chai et al. (2017). The items for the efficacy for designing STEM e-learning

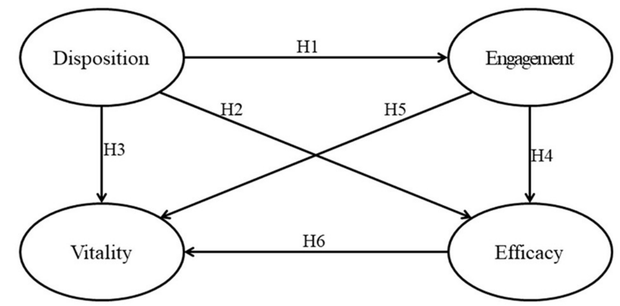

FIGURE 1 | Structural equation model of the design-associated variables of teachers.

items were adapted since the original survey was designed to investigate the efficacy of teachers for designing technological pedagogical content knowledge. Lesson design engagement items were constructed for this study to assess the STEM design effort of teachers in terms of identifying learning goals, generating teaching ideas, designing relevant STEM learning activities, and revising the design. These design-thinking activities in the lesson design processes have been identified earlier (Dick and Carey, 1996; Chai and Koh, 2017), and Koh et al. (2015) argued that teachers could create technology-integrated lessons through the design-thinking process. This study follows a design-thinking approach and constructs the lesson design engagement items. For example, one item was "I consider including new strategies that may facilitate students learning." Vitality (four items, $\alpha = 0.80$–0.89) was adopted from the study by Bostic et al. (2000) that measured the feeling of teachers of being alive and alert during the design-thinking process. An example item is "When I am engaged in lesson design, I feel alive and vital." All items were scored on a 5-point Likert scale (i.e., 1 = strongly disagree to 5 = strongly agree). The survey was reviewed by three education professors to ensure content validity.

Data Analysis

We employed partial least squares structural equation modeling (PLS-SEM) using SmartPLS 3 software (Ringle et al., 2015). PLS-SEM was used since it produces similar results to SEM, with advantages in coping with a small sample size than SEM (Hair et al., 2019). We examined the measurement and structural models following a two-step approach: validation of the measurement models and examination of the structural relations among the latent factors. The research framework contains four components, as depicted in **Figure 1**. The hypothesis testing was performed to assess the relationships proposed in this study as follows:

H1: Disposition toward design predicts lesson design engagement.
H2: Disposition toward design predicts efficacy for designing STEM e-learning.
H3: Disposition toward design predicts vitality.
H4: Lesson design engagement predicts efficacy for designing STEM e-learning.
H5: Lesson design engagement predicts vitality.

TABLE 1 | Results of the measurement model.

Latent construct	Item	Indicator loading	*T*-value	Cronbach's Alpha	CR	AVE	VIF
Disposition toward design	1	0.85	23.65	04	0.90	0.76	1.82
	2	0.89	41.79				2.19
	3	0.86	26.91				2.03
Lesson design engagement	1	0.74	14.13	8	0.86	0.60	1.41
	2	0.78	21.20				1.44
	3	0.81	17.34				1.76
	5	0.77	12.07				1.67
Efficacy for designing STEM e-learning	1	0.87	34.11	2	0.94	0.76	2.77
	2	0.85	24.72				3.12
	3	0.90	36.47				3.71
	4	0.91	44.86				3.67
	5	0.82	20.52				2.08
Vitality	1	0.88	38.51	9	0.92	0.75	2.50
	2	0.90	45.88				3.03
	3	0.83	13.26				2.10
	4	0.84	22.90				2.12

H6: Efficacy for designing STEM e-learning predicts vitality.

RESULTS

A PLS-SEM is composed of two sub-models. First, we examined the relationships between the observed data and the constructs in the measurement model, and second, we tested the hypotheses in the structural model (Hair et al., 2014).

Measurement Model

First, the psychometric properties of the survey to establish its reliability, validity, and collinearity are assessed. The reliability of variables was examined using Cronbach's alpha and composite reliability (CR). The Cronbach's alpha values of all the constructs were from 0.78 to 0.92 (>0.7) (**Table 1**). All the CR values ranged from 0.86 to 0.94 (>0.7), indicating good internal consistency (Hair et al., 2014). Convergent and discriminant validities were evaluated through loadings of indicators, the average variance extracted (AVE) values, and the square root of AVEs. The loadings of the items of indicators ranged from 0.74 to 0.91 (>0.7). The AVEs of the constructs ranged from 0.60 to 0.76 (>0.5), indicating the satisfactory convergent validity (Fornell and Larcker, 1981). As shown in **Table 2**, the square roots of AVE for all constructs were higher than their correlation coefficients with the other constructs (Fornell–Larcker criterion), indicating that the constructs possessed good discriminant validity (Chin, 1998). Finally, variance inflation factors (VIFs) for all variables were examined to check the collinearity of the constructs. The values for VIF were from 1.41 to 3.71 (<5) (Hair et al., 2014). The outcomes of reliability, convergent validity, discriminant validity, and collinearity in the PLS-SEM analysis confirmed that the adopted and adapted items in this study were reliable and valid.

TABLE 2 | Discriminant validity test results of the measurement model.

	1	2	3	4
1. Disposition toward design	0.87			
2. Lesson design engagement	0.44	0.77		
3. Efficacy for designing STEM e-learning	0.56	0.53	0.87	
4. Vitality	0.55	0.67	0.53	0.87

Diagonal elements are the square roots of the average variance extracted.

Structural Model

The structural model was assessed by examining the significant level of path coefficients in the model. As shown in **Table 3** and **Figure 2**, five significant predictive relations were observed in the model with path coefficients (β) ranging from 0.26 to 0.48. Disposition of teachers toward design positively predicted their perceived lesson design engagement ($\beta = 0.44$, $p < 0.001$), efficacy for designing STEM e-learning ($\beta = 0.40$, $p < 0.001$), and vitality ($\beta = 0.26$, $p < 0.01$), and lesson design engagement of teachers positively predicted their perceptions of efficacy for designing STEM e-learning ($\beta = 0.36$, $p < 0.001$) and vitality ($\beta = 0.48$, $p < 0.001$). However, the efficacy of teachers for designing STEM e-learning did not predict vitality ($\beta = 0.13$, $p > 0.05$). These results showed that, when the teachers possess a higher disposition toward designing STEM learning and lesson design engagement, they may exhibit a strong sense of efficacy for designing STEM e-learning and possess higher vitality.

DISCUSSIONS AND CONCLUSION

Since STEM education is interdisciplinary, the design of STEM curriculum involves a high degree of complexity (Chai, 2019). Teachers need to integrate the different STEM disciplines to design meaningful teaching and learning topics and activities.

TABLE 3 | Path estimated of the structural model.

Path estimates (hypotheses)	Path coefficient	Mean	Standard deviation	T statistics	*p*-value	Hypotheses supported?
H1: Disposition -> Engagement	0.44	0.45	0.07	6.10	<.001	Yes
H2: Disposition -> Efficacy	0.40	0.40	0.08	5.34	<.001	Yes
H3: Disposition -> Vitality	0.26	0.26	0.09	3.04	<.001	Yes
H4: Engagement -> Efficacy	0.36	0.36	0.07	4.78	0.003	Yes
H5: Engagement -> Vitality	0.48	0.49	0.08	5.95	<.001	Yes
H6: Efficacy -> Vitality	0.13	0.13	0.08	1.59	0.11	No

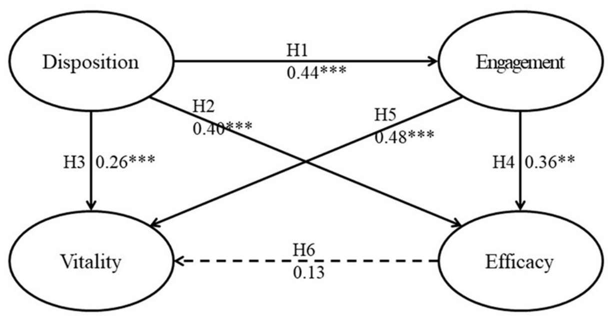

FIGURE 2 | Structural model of the design-associated variables of teachers. $^{**}p < 0.01$, $^{***}p < 0.001$.

However, in practice, most STEM educators lack experience in designing integrative STEM curricula, which may result in teachers having low efficacy for designing STEM e-learning and vitality. Thus, designing integrative STEM curricula is a major challenge in STEM education. In this study, a new instrument was designed to assess these design-associated variables. This study observes the key to create good STEM education depending on the design of teachers. The disposition of teachers toward design was defined as their propensity to deal with the inevitable uncertainties and ambiguities involved when they develop new pedagogies, understand the needs of students, generate teaching ideas, and design activities for STEM education. The disposition of teachers toward design facilitates iterative lesson design engagement necessary to create and refine the STEM curriculum continuously. Following (Chai and Koh, 2017) articulation, we defined the lesson design engagement of teachers as their commitment to creating new strategies and objectives and testing the ideas in relation to the learning processes of students. The iterative engagements improve the STEM lessons designed and promote the efficacy of teachers for designing STEM e-learning, which refers to their beliefs in their capabilities to design and implement effective STEM teaching strategies to bring about the desired learning outcomes. Finally, we defined vitality as the energetic feelings and excitement of teachers when designing STEM learning activities.

The results of PLS-SEM indicated a reliable measurement model with satisfactory convergent and discriminant validities. In other words, this study has validated four interrelated psychological factors that could be used to study the design-based work of teachers for integrated STEM education. Regarding the structural model, several positive associations were identified between the design beliefs, design behavior, perceived efficacy for designing STEM e-learning, and vitality of teachers in the design context as hypothesized. In particular, the disposition of teachers toward design predicted lesson design engagement, and both disposition toward design and lesson design engagement positively predicted efficacy for designing STEM e-learning and vitality. Since significant relationships were observed between the disposition of teachers toward design, lesson design engagement, and efficacy for designing STEM e-learning in this study, we considered that the teachers with a greater inclination to and involvement in the design-thinking process might possess higher expectations for effective STEM design outcomes. In general, the more design tendencies the teacher possessed, and the more engagement they reported, the higher efficacy they perceived, and the more feelings of being energized by the design activities they expressed. This is in line with previous studies showing that the design inclination of a person is likely to be positively associated with their belief in self-efficacy (Jong et al., 2020), involvement in design practice (Koh et al., 2015), and the optimistic outlook to embrace the uncertainties and ambiguities of design situation (Dong et al., 2015; Royalty et al., 2015).

The model depicts a positively associated web of factors that could help to address the need for STEM curriculum design (Hallström and Schönborn, 2019). It also implied that teacher educators might need to pay attention to understand the disposition of teachers toward design and highlight the ill-structured nature of design challenges (Margot and Kettler, 2019). This could address the expectations of teachers of what to expect when they participate in STEM curriculum design activities that could be riddled with uncertainties and ambiguities. In addition, teachers also need to understand the iterative design-thinking engagement needed over an extended period of time (Dorst and Cross, 2001). The findings indicate that the teachers with a stronger disposition toward design are more adept in being engaged in iterative design-thinking processes (Koh et al., 2015). In contrast, the model also implied that teacher developers have to provide adequate support for design thinking during the iterative processes of STEM lesson design so that the activities could foster the efficacy of teachers for designing STEM e-learning (Chai and Koh, 2017). This would likely lead to a sense of vitality, which is a positive and desirable outcome of the complex interdisciplinary design effort.

Teacher efficacy for designing STEM e-learning denotes the beliefs of teachers about their ability to design and has reciprocal relations in goal-directed STEM activities (Lent and Brown, 2006). Studies have also reported that the engagement of teachers in design activities influences their self-efficacy beliefs (Salanova et al., 2011; Simbula et al., 2011; Chai et al., 2020). In this study, the teachers were engaged in professional development. The experience of engagement could generate opportunities for a sense of mastery in designing integrative STEM activities, which is integral to developing self-efficacy beliefs (Bandura, 1997). In this view, the engagement of teachers at design work as a form of professional development may predict their perceived capability of performing design work.

Bell (2016) indicated that teachers who are energized might be capable of designing a well-integrated STEM learning context that could foster the motivation of students to learn STEM, development of problem-solving skills, and pursuit of a related degree and career. In other words, high vitality could initiate cycles of positive growth toward STEM design and teaching expertise. However, the self-efficacy of teachers may be reduced due to burnout, and promoting a healthy classroom environment relies on their high self-efficacy (Flook et al., 2013). Thus, it is important to sustain the efficacy of teachers for designing STEM e-learning and vitality for STEM education. As depicted in **Figure 2**, the sustenance hinges upon lesson design engagement with the disposition toward design as the predictor. Support to foster continuous lesson design engagement and disposition toward lesson design is thus important. School leaders have to offer the structure for teachers to engage in design-thinking, while teacher educators may have to play the role of supporting teachers' design thinking (Chai, 2019; Chai et al., 2020). As interdisciplinary STEM education is a complex endeavor, it should also be noted that the long-term efforts are likely to be needed.

Chai et al. (2017), Dong et al. (2015), and Li et al. (2019) have emphasized the importance of design beliefs. This study explores how the design traits of individuals impact lesson design engagement, efficacy for designing STEM e-learning, and vitality. This study observes that disposition toward design and design-thinking competencies might play a significant role in the design attitudes of teachers and involvement in designing STEM learning. Specifically, the strong disposition of teachers toward design indicates that they feel comfortable with the ambiguous design problems and that they may respond with design thinking to overcome these problems (Chai et al., 2017). The significance of the effect of disposition toward design on lesson design competencies indicated that when teachers feel capable of managing design problems, their design competencies also improved, enabling them to effectively deal with the demands of design situations (Koh et al., 2015). Teachers who possessed a stronger disposition toward design and capacity for designing STEM learning may feel excited as STEM designers (Kali et al., 2015). This finding suggests that, when confronting a new design situation that teachers have not experienced before, those with high tolerance toward ambiguity may be more engaged in regulating their design thinking to deal with the design tasks. Teachers with a high disposition toward design could thus be a good choice for school leaders when they need teachers to innovate teaching and learning. This study also implies that engaging in STEM education is essentially a design-intensive process. If educational systems or peer communities of teachers could provide professional development to facilitate the engagement in the lesson design processes, teachers could feel supported in designing STEM learning, which could subsequently increase their enthusiasm for developing and implementing STEM learning (Intrator and Kunzman, 2007; Ross and Bruce, 2007; Meijer et al., 2009).

This study has some limitations. First, the sample size was relatively small. Future studies may enlarge the research sample size. Second, the survey was a self-reported assessment. We attempted to assess the design thinking of teachers, but the design is a dynamic process that depends on the context. A valid structural model with long-term instructional intervention could be considered in future studies. Third, the aim of this study was to focus on validating the proposed conceptual model and the corresponding hypotheses. Background variables, such as gender, age, years of teaching experience, were gathered in the data collection process. These data could be further analyzed using the multigroup analysis or between-group analysis in PLS-SEM, as a means of testing predefined data groups to determine if there are significant differences in group-specific parameter estimates. Fourth, this study was conducted in the context of secondary STEM education; nevertheless, we believe that the developed model and the related work presented in this study are applicable to other educational contexts, such as learning and teaching of other subjects or interdisciplinary subjects in K-12 education. Despite these limitations, the findings of this study contribute to the literature by identifying the psychological and pedagogical determinant factors for designing STEM learning.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because requests need to be vetted by the research ethic committee. Requests to access the datasets should be directed to cschai@cuhk.edu.hk.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Chinese University of Hong Kong. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and have approved the submitted version of the manuscript.

ACKNOWLEDGMENTS

We are grateful to the teachers for their participation in the experiment.

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APPENDIX 1

TABLE A1 | The four latent variables and their assessment items.

1. Disposition toward design
I am comfortable with the presence of uncertainty.
I am comfortable to explore conflicting ideas.
I am comfortable to deviate from established practices.
2. Lesson design engagement
I consider including new strategies that may facilitate students learning.
I write down clearly the lesson objectives to be achieved.
I source for relevant information and materials to make the lesson interesting.
I conduct the lesson as planned to test out the feasibility of the lesson (*item deleted*).
I revise the lesson objectives and strategies when needed.
3. Efficacy for designing STEM e-learning
I can formulate in-depth discussion topics about the STEM content knowledge for students' online discussion.
I can help students to construct and share different representations of the STEM knowledge using appropriate ICT tools.
I can design online inquiry activities to guide students to make sense of the STEM knowledge with appropriate ICT tools.
I can create new activities that use a range of web-based tools to facilitate students' knowledge building for the STEM project.
I can generate new ideas about how to use technology in a pedagogically appropriate way to teach the subject matter.
4. Vitality
When I am engaged in lesson design, I feel alive and vital.
When I am thinking about my lesson design, I have energy and spirit.
When I am designing lesson, I nearly always feel alert and awake.
When I generate new lesson ideas, I feel energized.

One item "I conduct the lesson as planned to test out the feasibility of the lesson." was deleted, because the factor loading was under 0.7.

frontiers in Psychology

BRIEF RESEARCH REPORT
published: 08 October 2021
doi: 10.3389/fpsyg.2021.719648

Emotional and Cognitive Preservice Science Teachers' Engagement While Living a Model-Based Inquiry Science Technology Engineering Mathematics Sequence About Acid-Base

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OPEN ACCESS

Edited by:
David Gonzalez-Gomez,
University of Extremadura, Spain

Reviewed by:
Heike Itzek-Greulich,
Thomas Morus Secondary School,
Germany
Jin Su Jeong,
University of Extremadura, Spain

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Specialty section:
This article was submitted to
Educational Psychology,
a section of the journal
Frontiers in Psychology

Received: 02 June 2021
Accepted: 06 September 2021
Published: 08 October 2021

Citation:
López-Banet L, Aguilera D,
Jiménez-Liso MR and
Perales-Palacios FJ (2021) Emotional
and Cognitive Preservice Science
Teachers' Engagement While Living
a Model-Based Inquiry Science
Technology Engineering Mathematics
Sequence About Acid-Base.
Front. Psychol. 12:719648.
doi: 10.3389/fpsyg.2021.719648

Science inquiry and modeling activities have been proved to heighten emotional situations; therefore, research about emotions should aim to identify which activities promote student engagement with Science, Technology, Engineering and Mathematics fields through multidimensional models that include emotional and cognitive engagement. This research is focused on science teachers' need to carefully review their classroom instructions to ensure that students are provided with opportunities to develop appropriate understandings of acid/base models (and their concepts). To achieve this, we have implemented a short model-based inquiry acid-base instructional sequence in the context of a TV-spot about chewing gum. A descriptive, non-experimental quantitative methodology with a heuristic (emotional: self-report questionnaire; and cognitive: self-regulation questionnaire) has been used to analyze what Pre-Service Secondary Education Teachers from several Spanish universities recognize to have learned and felt in each activity. Differences regarding knowledge declared by the participants were identified in all the tasks from before to after carrying them out. Furthermore, the results seem to indicate that there are significant relationships between the knowledge and the emotions, being different depending on the skill involved. Significant correlations between emotions have been found. However, there were no significant correlations with either rejection and knowledge or with other emotions, which points to emotional engagement. Generally, no significant differences were identified between emotions and gender or universities, with some exceptions between genders in two tasks. Thus, the results led us to reflect on the instructional sequence implementation's ability to bring awareness to the learning process and how it produces multidimensional engagements.

Keywords: cognitive engagement, emotional engagement, gender roles, model-based inquiry (MBI), preservice chemistry secondary teachers, scientific methods, skills development, STEM-science technology engineering mathematics

INTRODUCTION

Daily life situations in which people must use scientific knowledge of acids and bases are numerous and imply making decisions about certain actions that involve socio-scientific controversies in the face of unfounded advertisements about health or home remedies. Nevertheless, the scarcity of acid/base contents to explain everyday phenomena at levels below high school, both in the official curriculum and in textbooks (Jiménez-Liso et al., 2002), makes it difficult for teachers to see the need to introduce them to Secondary School or to have teaching resources to lean on. Therefore, a specific acid/base training for teachers that integrates these chemical contents with pedagogical content knowledge is essential. To achieve this, it is necessary to design instructional sequences of authentic practices for teachers, with a clear and recognizable teaching approach that connects this knowledge with everyday phenomena and that also promotes epistemological knowledge.

The role of emotions during teacher training has been scarcely researched even though the process of learning to be a science teacher is a situated social practice that is infused with emotion (Bellocchi et al., 2014). It has been proven that science inquiry and modeling activities can heighten emotions (Jimenez-Liso et al., 2019). We wanted, thus, to focus on measuring the instructional sequence designed for pre-service teachers on a combination of multiple dimensions of engagement. As Sinatra et al. (2015) mentioned, engagement in the scientific practices as a whole has not been extensively researched, and therefore the specific connections among the behavioral, cognitive, emotional, and agentic dimensions of engagement are speculative.

In this paper, we want to measure an integrated view of engagement that considers multiple dimensions in interaction (some of the dimensions of engagement overlap). Therefore, we address this issue by implementing and evaluating the Model-Based Inquiry (MBI in advance) instructional sequence's effect on Pre-Service teachers' (PSTs in advance) emotional and cognitive engagement related to acid/base contents as they develop professional competence in this field.

THEORETICAL FRAMEWORK

The teaching and learning of scientific practices in which students are engaged is emerging in many countries (Jaber and Hammer, 2016). Students learn not only the knowledge but also scientific skills in each practice, and they are able to recognize a broad spectrum of scientific methods rather than just one (Halawa et al., 2020). However, PSTs may not notice all of these benefits; because they lack prior professional experience, their spontaneous conceptions about teaching, which are rooted in their extensive experience as students, represent a real obstacle to change in teaching (Tobin and Espinet, 1989). To achieve substantial changes (Milner et al., 2012) the teaching approach itself must respond to the proposed MBI approach so that future teachers are trained following the same approach that they are to implement with their students (van Zee and Roberts, 2001; van Zee, 2006; Wee et al., 2007). In this sense, different studies have shown the importance and effectiveness of future teachers, during their training process, experiencing innovative instructional sequences that serve as a model teaching approach (Wandersee et al., 1994; Jimenez-Liso et al., 2021). Such instructional sequences consistent of integrated learning of content, teaching strategies, and students' ideas. Some authors have gone further by suggesting that future teachers can participate in cycles of planning, teaching, and reflection on their experiences in the schools (Parker, 2006; Zembal—Saul, 2009).

Furthermore, chemistry is in a good position to contribute to achieving one of the United Nations (2021) Sustainable Development Goals (SDGs), that of gender equality, and to respond to UNESCO (2017) suggestion that science teachers can positively influence girls' interest in STEM subjects. Chemistry can help shape young women's future choice of professional STEM careers, from an inclusion perspective and can play a prominent role in the treatment of biases with a model of good systemic practices. The development of practical skills, training in cultural competence, and promotion of approaches aimed at improving equality, diversity and inclusion, should help to achieve the SDGs (Mehta et al., 2018). For these reasons, in this theoretical framework, we chose to focus on the MBI teaching approach, on justifying the need for an initial training of eminently practical teachers and on the cognitive and emotional dimensions that will be the object of measurement of the instructional sequence evaluation.

Model-Based Inquiry

Many international research projects and reports opt for the MBI approach—which aims to promote the learning of scientific competence by involving students in the design and development of their own scientific research—due to its advantages of motivating students and favoring both the learning of science and the characteristics of scientific activity. The MBI model presents learning as a dynamic process aimed at building descriptive, explanatory, and predictive knowledge, and producing an evolution of the students' ideas as they wonder about natural events (Khan, 2007; Windschitl et al., 2008; Schwarz, 2009). For this reason, inquiry and modeling are considered two of education's purposes to which scientific disciplines must contribute to involve students in the practice of science.

Jiménez-Liso et al. (2018) described the implementation, among Secondary Education students, of a sequence of inquiry and modeling on the acid/base contents through the use of pH-meters that allow students to explain and predict outcomes based on acid/base phenomena. In addition to the conceptual learning objective, such as understanding the difference between dilution and neutralization, the sequence promotes the development of research skills, and helps students to be aware of the constructed procedural knowledge. Throughout the process, students are dedicated to raising questions and expressing, justifying, and discussing their ideas through different forms of communication (oral and written language, graphics, drawings, etc.), designing the search for tests to contrast their own ideas, analyzing results, and obtaining and discussing conclusions about the results and the involved processes. At the end, students recognize the need to use a model to explain the new phenomena and make a proposal that is jointly evaluated and reviewed.

Preservice Teachers Training

Secondary chemistry teachers do not always include scientific practices in laboratory sessions (Boesdorfer and Livermore, 2018) or align classroom activity structures with the Next Generation Science Standards (NGSS) recommendations (Criswell and Rushton, 2014). Conceptions influenced by traditional practices, such as the lack of students' participation in establishing their own scientific ideas, or a teacher's excessive control over the completion of the task over the understanding of it, represent a limiting factor in teachers' implementing activities by inquiry and modeling. For these reasons, improving teachers' understanding could encourage more student inclusion in science classes (Donnelly et al., 2014). A guided inquiry and modeling instructional framework with science methods instruction can enable PSTs to apply their knowledge to enactments of reform-oriented science teaching approaches (Schwarz and Gwekwerere, 2007). It is recommended that teachers focus not only on content knowledge, but also on procedural and epistemic knowledge as well as on scientific understanding of phenomena with its proper interpretation (Bellová et al., 2017). During initial training, MBI approaches lead to PSTs becoming aware of how science is learned (both conceptual and procedural contents) and stating that they intend to implement scientific practices as future teachers (Jimenez-Liso et al., 2019). In order to offer an alternative teaching approach to what PSTs experienced as students, we selected an MBI instructional sequence that achieves that goal and that has been designed to require learning from STEM areas.

Cognition and Emotions

Human behavior regarding approach or avoidance is determined not only by the reflective evaluation of its anticipated consequences, but also by affective impulses. Thus, emotion and behavior are related at least reflexively and impulsively (Strack et al., 2016). Therefore, we will pay special attention to studies based on emotional frameworks, which have begun to associate emotions with participation in challenging projects and creative problem solving.

It is essential to assume as part of teachers' academic training that including the development of emotional skills has a great impact on their professional and personal enrichment (Valente and Lourenço, 2020). However, previous research studies have only emphasized the cognitive and behavioral components, excluding the emotional dimension, which currently constitutes a line of research in science education that is in constant growth and is in urgent need of examination (Fortus, 2014; Mellado et al., 2014; Bellocchi et al., 2015; Zembylas, 2016). Emotions are present throughout engagement with science practices, both students and scientists, which thus calls for pursuing deeper understanding (Jaber and Hammer, 2016). It is essential to train emotionally competent teachers who know how to diagnose and self-regulate their emotions (Bisquerra Alzina and Pérez Escoda, 2007). The first teaching experiences are emotionally very strong and can set behavioral strategies (Mellado et al., 2014). Disciplinary engagement in science is characterized by the experience of epistemic affect, such as the excitement of having a new idea or the irritation at an inconsistency (Jaber and Hammer, 2016). Jimenez-Liso et al. (2019) made PSTs aware of positive emotions, like satisfaction or interest experienced when they were "doing scientific practices." Therefore, limiting teaching and learning to methods solely aligned with a cognitive, rational perspective, without emotive elements of learning, could be unproductive whereas aesthetic experiences promote more science learning (Girod et al., 2010).

Gottlieb et al. (2018) determined that awe and scientific thinking are positively associated; thus, engaging in science requires a disposition to revise beliefs about seeing new evidence. Awe is considered the emotional state most likely to impact outcomes in science learning (Valdesolo et al., 2017) and implies the accommodation of new information that cannot be assimilated into preexisting schemas (Keltner and Haidt, 2003), according to Piagetian theories of cognition (Piaget, 1971). Moreover, when a sudden awareness of connections between concepts arises without a conscious understanding of the processes then the tacit processing to reach a conscious outcome is allowed. For tacit processing to achieve a conscious result, students need to be given enough time to engage in problem solving, or to think about answers to questions in class, which time is essential to their becoming aware of how they learn science (Brock, 2017).

OBJECTIVE

To analyze the PSTs perceptions of students' learnings after they experience this sequence of activities by inquiry and modeling, we need the PSTs to become aware of the importance of linking the cognitive and the affective in learning. Thus, we propose having groups of teachers implement a sequence of inquiry and modeling on the effects of chewing gum on the mouth's pH level to focus the PSTs on the teaching approach at the same time while they, themselves, learn and reflect on what they learned: how they learned and how they felt during the instructional sequence implementation.

In addition, this implementation will allow us to comprehensively gauge their participation in both the cognitive and emotional dimensions.

This research is focused on science teachers' need to carefully review their classroom instruction to ensure that PSTs are provided with opportunities to develop appropriate understandings of the acid/base models (and their concepts). Thus, the main objective of this research is to allow future teachers to become aware of the facts of acid/base contents (self-regulation of learning), how they learn (leading to an explicit discussion on the phases of inquiry and modeling), how they help others to learn, and their relationship with emotions (what emotions emerge during the implementation practice).

METHOD

Description of the Instructional Sequence

To achieve the abovementioned aims, two teachers (first and third authors of this paper) implemented a short MBI acid-base instructional sequence (length 2 h) in the context of a TV-spot about chewing gum (López-Banet et al., 2021). The implementation was composed of ten tasks or key moments that PSTs responded to individually before sharing and discussing them with the whole class. T1–T9 are included in **Table 1**, and T10 consists of the self-regulation of learning and feelings. The sequence described above requires coordinating diverse disciplines that constitute the STEM field (Martín-Páez et al., 2019), by encompassing chemical contents (Science), the understanding of a logarithmic scale (Mathematics) through a dynamic visualization with sensors (Technology) and generating a variety of experimental designs (Engineering). Furthermore, both the interpretation of several types of resources (such as textual, visual, or sound) and the skill of creating an explanatory model for a scientific question, leads to a natural connection with the visual arts. Thus, a STEAM view is needed from the interdisciplinary of the teaching proposal, which is further enriched by the incorporation of knowledge and skills from all areas (López-Banet et al., 2021).

Research Sample

Two groups of PSTs in training participated in this study. They were students of a two-semester academic calendar master's degree at two public universities, which is compulsory for earning a certification for secondary school teaching in Spain. Both groups consist in a variety of students participating in the same MBI sequence that it was taught by two teachers with different profiles of their respective master's degrees, at University of Almería and Murcia (different training plan), in the same academic term (2020/21). These circumstances are unique and prevent from having a greater sample size. It is worth mentioning that the participants had never experienced MBI instructional sequences when they enrolled in this master's program.

The first group was 27 PSTs (18 women and 9 men) from the University of Almería, who had previously studied Biology (11), Biotechnology (5), Chemistry (2), Biochemistry (2), Environmental sciences (2), Food Technology (2), Geology (2) and Pharmacy (1). The second group had 18 students (11 women and 7 men) from the University of Murcia, who had pursued Chemistry (6), Physics (6), Biochemistry (4), Chemical Engineering (1) and Food Technology (1).

Instrument for Evaluating Pre-Service Teachers Engagement

In order for PSTs to notice the what and how of learning as well as what emotions they felt, at the end of the instructional sequence we added *in situ* measures of the self-regulations of learnings and emotions with a questionnaire that has a minimal disruption of the flow of PSTs learnings, because it is a task (T10) inside of the instructional sequence with coherence and sense to teachers and students (Jimenez-Liso et al., 2021). Emotional engagement is addressed by the presence of emotions associated with the learning outcomes (such as interest and concentration) and the absence of emotions that would hinder the task (rejection). The cognitive dimension refers to all the strategies that students must develop in order to build significant learning processes, including self-regulation of learning.

We used a descriptive, non-experimental quantitative methodology using a Knowledge and Prior Study Inventory (KPSI) as self-regulation questionnaire (Tamir and Amir, 1981; Jimenez-Liso et al., 2019) and emotions recognized by PSTs in the key moments of the applied inquiry sequence. The KPSI consists of a self-report on ten emotions: nine of them (rejection, concentration, insecurity, interest, boredom, confidence, satisfaction, dissatisfaction, and bashfulness) were in a previously validated questionnaire (Jimenez-Liso et al., 2019). We also included another emotion (surprise) because surprising observations could later elicit the "aha" or awe moment, which scientists have linked to the learning process and to situations of discovery (Cuzzolino, 2021). PSTs were able to select the emotion label related to all the key moments following the sequential order of the model-inquiry sequence. In order to self-regulate the knowledge, before and after the sequence was implemented, PSTs answered on a scale of 1 to 5 (1: I know nothing; 2: I know a little; 3: I know well; 4: I know it very well; and 5: I can explain it to a friend) for each key moment, in chronological order.

Data Analysis

A descriptive analysis was carried out for the knowledge variable (minimum, maximum, median, mean, and standard deviation) and a frequency analysis for the different emotions under consideration. Non-parametric tests were also applied, as the sample size as well as the nature of the data recommend it. The U-Mann Whitney test was used to determine significant differences among independent samples, according to the university to which the students belonged and to their gender. The Wilcoxon W test was used to verify the significance of the differences between the pre and post results of the knowledge variable. The Spearman correlation coefficient was calculated to determine the relationship between the knowledge reached by the students in the post-test phase and the emotions experienced during the experience. Also, in order to determine the relationship between gender and emotions, Pearson's Chi-square was calculated. Finally, Cohen's d (effect size, ES) was calculated for the knowledge variable. The indications of Cohen (1988) were followed to interpret the ES.

RESULTS

No significant differences in knowledge were identified based on gender nor based on the students' universities in any of the tasks, with the exception of T2 (How can we prove that they are acidic?). Specifically, at the time prior to performing the second task, there were significant differences (p. = 0.005) between the University of Murcia (mean = 3.61; Standard dev. = 0.979) and the University of Almería (mean = 2.74; Standard dev. = 0.813),

TABLE 1 | Knowledge declared by the participants for the 9 tasks, before and after carrying them out.

Task (before/after)	N	Minimum	Maximum	Median	Mean	Standard deviation	Evolution*	Z	.p	ES
T1: What are acid substances (before)	45	2	5	3	2.80	0.869	1.2	−5.259	<0.01	1.353
T1 (after)	45	2	5	4	4.00	0.905				
T2: How can we prove that they are acidic? (before)	45	1	5	3	3.09	0.973	1.27	−5.203	<0.01	1.445
T2 (after)	45	2	5	5	4.36	0.773				
T3: Hypothesis on the effect of chewing gum on the pH of the mouth (before)	45	1	5	1	1.58	0.783	2.49	−5.478	<0.01	2.616
T3 (after)	45	1	5	4	4.07	1.095				
T4: Design and evaluate experiments to test your hypothesis (before)	45	1	5	2	2.20	0.944	1.53	−5.597	<0.01	1.530
T4 (after)	45	2	5	4	3.73	1.053				
T5: Chewing gum pH data analysis: coincidences and discrepancies (before)	45	1	5	2	1.80	0.919	2.13	−5.597	<0.01	2.207
T5 (after)	45	1	5	4	3.93	1.009				
T6: If chewing gum dilutes acids or neutralizes them (before)	45	1	5	1	1.56	0.841	2.53	−5.704	<0.01	2.641
T6 (after)	45	1	5	4	4.09	1.062				
T7: The mathematical zoom: liters of saliva to "neutralize" the acids in the mouth (before)	45	1	5	1	1.62	0.886	2.34	−5.709	<0.01	2.510
T7 (after)	45	1	5	4	3.96	0.976				
T8: "Pac-man" model to explain why the pH drops in the mouth after chewing Orbit gum (before)	45	1	5	1	1.47	0.842	2.95	−5.862	<0.01	3.759
T8 (after)	45	2	5	5	4.42	0.723				
T9: "Pac-man" model to explain why the balloon is inflated (baking soda and vinegar). Make sense of the chemical formulation (before)	45	1	5	1	1.58	0.839	2.71	−5.770	<0.01	3.222
T9 (after)	45	2	5	4	4.29	0.843				

**Evolution in the average of the knowledge perceived in each item of the questionnaire KPSI (before and after).*

being equated after the development of the activity, at which time there were no significant differences. This data could be due to previous academic training, since at the university in which a lower initial value was obtained, they have more varied degrees, the majority being from the field of biology, while practically all the university students who obtained a higher value had degrees whose contents were closer to those dealt with in the sequence. These factors could explain the higher initial value. For example, those with the qualifications of biology, environmental sciences, or geology gave scores of less than 3 on knowing this task, while those with degrees in chemistry, physics, and biotechnology gave scores of greater than 3 (Chemistry graduates averaged scores were 3.88). **Table 1** includes the values on their learning, which were perceived by the participants regarding each task.

On the other hand, significant differences were identified in the nine tasks from before to after carrying them out (**Table 1**), with an increase of more than 2.5 after completing the following tasks: 6 (If chewing gum dilutes acids or neutralizes them); 8 (the "Pac-man" model to explain why the pH drops in the mouth after chewing Orbit gum); and 9 ("Pac-man" model to explain why the balloon is inflated), which increase seems to indicate that the PSTs perceived that they learned new knowledge about the effect of chewing gum, as well as they developed a model to explain what happens (**Figure 1**). In addition, the obtained ESs indicate substantial progress in terms of the students' perceived knowledge gains (**Table 1**).

Regarding the emotions they manifested throughout the sequence, in general there was a high interest in the activity as well as concentration and surprise (**Figure 1**).

Generally, no significant differences were identified between emotions and gender, with the following exceptions: Women ($N = 19$) manifested concentration to a greater extent than did men ($N = 9$) in task 1 ($\chi^2 = 4.543$; $p. = 0.033$); and in task 4, women ($N = 10$) also manifested greater insecurity ($\chi^2 = 5.114$; $p. = 0.024$) and greater dissatisfaction (women $N = 6$; men $N = 0$) ($\chi^2 = 5.538$; $p. = 0.019$).

With regards to the differences between universities, the students from UAL ($N = 12$) showed significantly more insecurity than did those from UMU ($N = 0$) ($\chi^2 = 10.909$; $p. = 0.001$) and more dissatisfaction (UMU $N = 0$; UAL $N = 6$) ($\chi^2 = 4.615$; $p. = 0.032$) in task 4 (Design and evaluate experiments to test your hypothesis). In task 5 (Chewing gum pH data analysis), UAL students ($N = 7$) showed significantly more insecurity than did

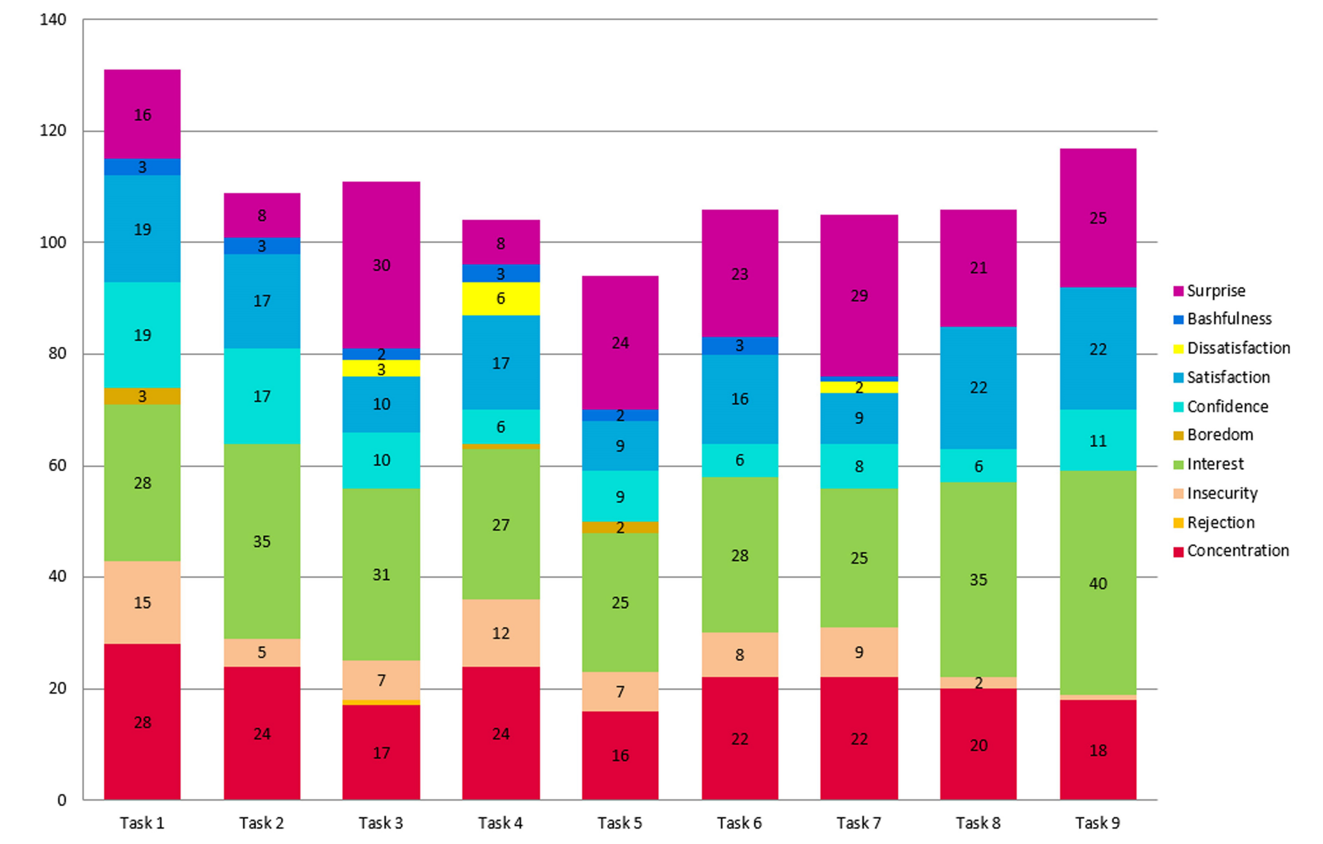

FIGURE 1 | Emotions experienced by the 45 participants of UAL and UMU.

TABLE 2 | Correlations between knowledge declared by the 45 participants (posttest) and emotions.

Task		Concentration	Rejection	Insecurity	Interest	Boredom	Confidence	Satisfaction	Dissatisfaction	Bashfulness	Surprise
T1	Knowledge	0.011	.	−0.317*	−0.084	−0.327*	0.352*	−0.061	.	−0.153	0.006
T2	Knowledge	0.023	.	−0.400**	−0.098	.	0.384**	0.144	.	−0.454**	−0.017
T3	Knowledge	0.258	0.149	−0.045	0.030	.	0.202	0.088	−0.407**	−0.319*	0.062
T4	Knowledge	0.073	.	−0.231	0.065	0.030	0.502**	0.240	−0.455**	−0.093	−0.218
T5	Knowledge	0.193	.	−0.203	0.065	−0.183	0.133	0.133	.	−0.297*	−0.110
T6	Knowledge	-0.183	.	−0.189	0.021	.	0.156	0.254	.	0.029	0.051
T7	Knowledge	0.029	.	−0.543**	−0.002	.	0.271	−0.036	0.254	−0.171	0.186
T8	Knowledge	0.093	.	−0.107	0.083	.	0.124	0.298*	.	.	0.054
T9	Knowledge	0.157	.	−0.95	0.298*	.	−0.037	0.189	.	.	0.171

**The correlation is significant at the 0.05 level (bilateral). **The correlation is significant at the 0.01 level (bilateral).*

those from UMU ($N = 0$) ($\chi^2 = 5.526$; $p. = 0.019$). In task 6 (If chewing gum dilutes acids or neutralizes them) the UAL students ($N = 8$) showed more insecurity than did those from UMU ($N = 0$) ($\chi^2 = 6.486$; $p. = 0.011$), while those from UMU ($N = 13$) exhibited more surprise than did those from UAL ($N = 10$) ($\chi^2 = 5.351$; $p. = 0.021$). Likewise, in task 6 the UAL students ($N = 6$) showed more confidence than did UMU students ($N = 0$) ($\chi^2 = 4.615$; $p. = 0.032$). Finally, in task 8 ("Pac-man" model to explain why the pH drops in the mouth after chewing gum) the UAL students ($N = 6$) experienced a greater degree of confidence than did the UMU students ($N = 0$) ($\chi^2 = 4.615$; $p. = 0.032$). It is worth mentioning that these results should be taken with caution since some of the significant differences may be due to the small number of students participating in the study. Thus, some of the emotions identified by UAL students have not been identified by any of the UMU (confidence, in tasks 6 and 8, insecurity

TABLE 3 | Correlations between emotions declared by the 45 participants (posttest).

	Concentration	Rejection	Insecurity	Interest	Boredom	Confidence	Satisfaction	Dissatisfaction	Bashfulness	Surprise
Concentration										
Rejection										
Insecurity	T4: −0.363*									
Interest	T5: −0.478** T7: −0.427** T8: −0.371*		T5: −0.384**							
Boredom			T1: −0.378*	T1:0.343*						
Confidence			T1:0.318*							
Satisfaction	T7: −0.400**			T7: −0.335*		T6: −0.528** T7: −0.349*				
Dissatisfaction			T3: −0.377* T4: −0.355*				T4:0.306*			
Bashfulness			T2: −0.472** T3: −0.502** T4: −0.443** T6: −0.342* T7: −0.302*			T7: −0.324*	T1: −0.313* T7: −0.302*	T3: −0.807**		
Surprise				T1: −0.387**		T5:0.423**				

**The correlation is significant at the 0.05 level (bilateral); **The correlation is significant at the 0.01 level (bilateral).*

in tasks 4, 5, and 6, dissatisfaction in task 4), and significant differences may result as a consequence of the fact that the UMU group is smaller.

Regarding the correlations between emotions and knowledge (**Table 2**), emotions were coded dichotomously (appearing or not appearing).

The results indicate that the relationship between knowledge and emotions declared by PSTs were different depending on the skill involved, as shown in **Table 2**. Nevertheless, it seems that concentration, rejection, and surprise are not significantly correlated to knowledge. Thus, in order to go further, significant correlations between emotions have been found in 8 of the 9 tasks (**Table 3**).

Regarding the abovementioned emotions that are not correlated to knowledge, concentration appears to be negatively correlated to insecurity when the PSTs designed and evaluated experiments. Also, these emotions were negatively correlated with interest using several skills, such as analyzing data, figuring out the liters of saliva to "neutralize" the acids in the mouth and using a model to explain why the pH drops in the mouth after chewing the gum. Finally, concentration was also negatively correlated to satisfaction when they were calculating the liters of saliva. Thus, depending on the skill, concentration could be related to less insecurity, or interest or satisfaction. On the other hand, surprise was negatively correlated to interest when PSTs had to define an acid, thus they who acknowledged less knowledge manifested a greater surprise after the implementation of the sequence. Additionally, surprise and confidence were positively correlated with the analyzed data, which result could mean that they who were surer about this skill were more surprised when they realized the results. Finally, there were no significant correlations with either rejection and knowledge or with other emotions, which points to emotional engagement.

CONCLUSION

According to studies based on emotional frameworks, student engagement with school science and modeling activities is multidimensional (emotional, cognitive, and behavioral) (Mellado et al., 2014; Bellocchi et al., 2015; Jimenez-Liso et al., 2021). In the study reported in this article, special attention has been paid to analyzing the learning perceived by PSTs after experiencing an acid-base sequence of activities by inquiry and modeling to promote their awareness of the importance of the affective in learning.

In this paper, the results seem to indicate that there are significant relationships between the knowledge and the emotions expressed by the participants in all of the activities. In some tasks, expressing greater confidence or satisfaction was positively related to greater perceptions of learning. Moreover, the students who considered they had learned more declared that they felt emotions that imply security in relation to skills as responding to the problem, proposing an experimental design to solve it, as well as explaining what happens through the use of a model. In the case of using a model, knowledge would be related to greater satisfaction and interest, which result is similar to that of previous studies where PSTs declared satisfaction or interest when they were "doing scientific practices" (Jimenez-Liso et al., 2019). However, those who showed less learning mentioned negative emotions in tasks that involved skills, such as making hypotheses, developing experimental designs, and conducting data analysis. Moreover, in each of these tasks where PSTs recognized different emotions, some of them showed significant correlations between them.

These results constitute a sample of the nature of PSTs' emotional engagement with scientific practices considering diverse previous academic training and the students' gender. On the one hand, although previous formation would affect their initial ideas, the results are similar for the rest of the tasks. Moreover, the implementation of the STEM sequence with PSTs did not show significant differences by gender, neither in the perceived knowledge nor in their expressed emotions. Thus, the involvement of both boys and girls in sequences with meaning and emotional commitment constitutes a possibility to alleviate the gender gap in STEM studies.

Furthermore, previous studies have found that participants who recognized the usefulness of scientific practices for supporting science learning stated their intention to implement them as future teachers (Jimenez-Liso et al., 2019). Thus, we can conclude that the acid/base MBI instructional sequence that was put into practice with both groups of PSTs might help them to notice the connection between theory-practice and to become conscious of the importance of including the scientific practices as part of the teaching and learning process.

Finally, as the main limitation of this research is the sample size, future perspectives would include teaching the same MBI sequence to more participants enrolled in similar master's programs. This enlargement would allow not only to compare the obtained results but also to extend the conclusions regarding emotional engagement indicated by the present results.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The participants provided their written informed consent to participate in this study according to the Research Ethics Commission of the University of Murcia.

AUTHOR CONTRIBUTIONS

LL-B drafted the manuscript and implemented the proposal at University of Murcia (Spain). DA performed all the statistical determinations and analyzed data. MRJ-L designed the research and implemented the proposal at University of Almería (Spain). FJP-P discussed the results and revised the manuscript. All authors ensure that evidence-based claims were made, revisions to logical sequencing of ideas, editing the manuscript drafts, and conceptual input.

FUNDING

This work has been partially financed by the projects PGC2018-097988-A-I00, PID2020-116097RB-I00, and UAL2020-SEJ-D1784 funded by FEDER/Ministry of Science and Innovation (MCI) of Spain-State Research Agency (AEI) and P20_00094 funded by Andalusia Government.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 01 November 2021
doi: 10.3389/fpsyg.2021.722535

Prompting Socially Shared Regulation of Learning and Creativity in Solving STEM Problems

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Problem-based learning (PBL) is a widely recommended method in science, technology, engineering, and mathematics (STEM) education through which students develop their scientific knowledge by collaboratively solving real-world problems. PBL benefits from both the activation of creative thinking and from socially shared regulation of learning (SSRL)-a group-level phenomenon whereby students collectively share common perceptions of their collaborative learning process and co-construction of knowledge. The current study examines the influence of three types of support (question prompts designed to promote SSRL, creative thinking, or a combination of both) on the participation of individuals in SSRL processes and on their knowledge acquisition, using a sample of 104 seventh-graders in accelerated science classes. Individuals' participation through the different stages of SSRL (forethought, performance, and reflection) was assessed using video recordings, and their scientific knowledge was measured through pre-and post-intervention knowledge tests. While all groups improved their scientific knowledge, individuals receiving only SSRL support improved their participation in most stages of SSRL compared with those receiving creativity or combined support, and a control group which received no support. The findings strengthen the case for SSRL-directed question prompts as a means to enhance student engagement in problem-solving tasks.

Keywords: solving STEM problems, socially shared regulation of learning (SSRL), scientific creativity, middle school, collaboratively learning

OPEN ACCESS

Edited by:
Jin Su Jeong,
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Reviewed by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *09 June 2021*
Accepted: *04 October 2021*
Published: *01 November 2021*

Citation:
Michalsky T and Cohen A (2021) Prompting Socially Shared Regulation of Learning and Creativity in Solving STEM Problems. Front. Psychol. 12:722535. doi: 10.3389/fpsyg.2021.722535

INTRODUCTION

To cope with rapid developments in the information and technology age, individuals need to adapt to innovation. This, in turn, requires "21st-century skills," including creativity, critical thinking, research, questioning, problem-solving, and collaboration skills (Binkley et al., 2012; Nilsson and Gro, 2015; Häkkinen et al., 2017; OECD, 2018). Traditional teaching is not necessarily equipped to develop 21st-century skills (Nilsson and Gro, 2015), particularly in the teaching of science, technology, engineering, and mathematics (STEM) subjects (National Research Council, 2012a, 2015). This matters, because STEM education is key to helping students face the challenges of the 21st century and prepare them to become productive workers (Wan Nor Fadzilah et al., 2016).

An integrative framework for the teaching of STEM subjects emphasizes the value of problem-based learning (PBL), a pedagogical approach through which students develop their scientific knowledge by collaboratively solving ill-structured problems—i.e., open-ended problems allowing for multiple solutions and problem-solving paths (Kitchner, 1983; OECD, 2013; Hathcock et al., 2015; Häkkinen et al., 2017). The approach aims to develop skills, promote critical thinking, and teach scientific concepts through students' application of knowledge to practical, real-world problems. School standards which promote PBL include the U.S. Framework for K—12 Science Education (National Research Council, 2012a) and the Next Generation Science Standards (National Science Standards Education, 2013), among others.

Solving STEM problems also involves the application of creative thinking skills such as idea generation and development. Solving problems collaboratively can have an advantage over solving them individually, in that it can increase the potential for creative thinking processes to unfold (OECD, 2013). However, many things can go awry during students' collaborative work. Working collaboratively on a problem-solving task can introduce cognitive, emotional, and behavioral challenges which jeopardize the desired results (Hadwin et al., 2011; National Research Council, 2012b; Järvenoja et al., 2013).

Socially shared regulation of learning (SSRL) is a group-level phenomenon in which groups regulate their learning as a collective, for example by constructing shared task perceptions or shared goals (Järvelä et al., 2008; Hadwin et al., 2011). SSRL can be fostered in school settings, and has been shown to be effective when supported through the use of question prompts (Järvelä and Hadwin, 2013; Järvelä et al., 2015). Such support mechanisms are intended to help students overcome the cognitive, emotional, and behavioral challenges that accompany learning in groups. However, determining what sorts of support are most effective for particular objectives is an ongoing issue in educational research (Panadero and Järvelä, 2015).

In what follows, we first outline the theoretical background around our major concepts: problem-based learning, creativity, SSRL, and support. We then introduce the current study examining three types of support, using question prompts: SSRL support, Creativity support, and Combined (SSRL and Creativity) support. After analyzing the data, we conclude by discussing the findings, their implications, the limitations of the study, and suggestions for future research.

THEORETICAL BACKGROUND

Effective STEM education should lead students to engage with elemental questions about the world, and with approaches used by scientists to investigate and answer these questions. Learning activities in which students conduct scientific investigations and try to solve real-life problems allow young people to develop their understanding of core ideas in science and engineering, encourage them to participate in public scientific discussions, and teach them to be critical when they encounter scientific information in everyday life (National Research Council, 2012a, 2015). These goals all require scientific knowledge and scientific creativity, in the sense of being able to generate, develop and assess potential problem-solving pathways and solutions (Hu and Adey, 2002; Vincent-Lancrin et al., 2019; Bi et al., 2020). Problem-based learning in STEM education provides an outstanding opportunity to enhance students' scientific knowledge and creative processes, allowing for promotion of scientific creativity (Hathcock et al., 2015; Lyre, 2018; Bi et al., 2020).

While learning in a PBL environment, students must take responsibility for their learning process by setting goals, monitoring, and reflecting from the beginning of the task until the end. Since this process doesn't come naturally or easily for many students, support for self-regulation of learning (SRL) can help (English and Kitsantas, 2013).

Collaborative Problem-Solving and Creative Thinking

Ayas and Sak (2014) defined scientific creativity as the ability to generate novel ideas or products that are relevant to the scientific context and have scientific usefulness or importance. Similarly, Hu and Adey (2002) defined scientific creativity as the ability to produce original products with social or personal value, designed for a certain purpose using given information. Under both definitions, solving problems in science requires students to explore their repertoire, to imagine a variety of routes to a solution, and frequently to create new combinations of knowledge or novel techniques (Hu and Adey, 2002; Hu et al., 2013).

To enhance the emergence of creativity during problem-solving exercises in class, it is important that the problem at hand be ill-structured in nature (OECD, 2013; Hathcock et al., 2015; Häkkinen et al., 2017). Having vague goals allows for multiple solutions and paths to achieve them (Kitchner, 1983), allowing students' creativity to unfold (Sullivan and Barbosa, 2017).

Solving STEM problems collaboratively also improves opportunities for creativity to emerge (Darling-Hammond, 2011; DiDonato, 2013; OECD, 2013; Häkkinen et al., 2017). By working together, individuals can combine their knowledge, effort, and understanding, allowing for meaningful creative processes (Sarmiento and Stahl, 2008; Ferreira and Dos Santos, 2009; Poutanen, 2016; Sullivan and Barbosa, 2017; Kupers et al., 2019). Indeed, many studies from the mid-1950s to today lend credence to the notion that working in a group increases the potential for creativity (Taylor et al., 1958; Larey and Paulus, 1999; OECD, 2013). However, groups can also become dysfunctional, making them less productive and less creative (Lencioni, 2002; Sawyer, 2012; Kirschner et al., 2018).

Such dysfunction can arise as the result of cognitive, metacognitive, motivational, and socio-emotional challenges (Van Den Bossche et al., 2006). Cognitive and metacognitive challenges can emerge through team members' failure to understand other members' thinking, or difficulties in negotiating multiple perspectives (Kirschner et al., 2008; Häkkinen, 2013). Motivational and socio-emotional challenges can arise due to divergence in group members' goals, priorities, and expectations (Järvelä et al., 2008). These challenges can reflect the involvement of students with different levels of knowledge, motivation, skills, and engagement in the group activity. Isohätälä et al. (2017) note that not all team members will make the same contribution to the team's work. In their study, they identified three levels of participation: active conversing (where the student contributed to the joint discussion), attunement (where the student did not substantially contribute to the joint discussion but showed signs of joint attention), and non-responsiveness (where the student did not contribute and showed few or no signs of attention). A high level of student participation increases the likelihood that SSRL processes will occur. Therefore, categorization of participation levels may come in useful when trying to understand the effect of an intervention on SSSL.

Regulation of Learning

Regulation of learning is an intentional process in which individuals take control of their own thinking (cognition), actions (behavior), and beliefs (motivation, emotions) to successfully complete a learning task (Zimmerman and Schunk, 2011). The challenges inherent in collaborative work mean that group-level regulation of learning, or SSRL, becomes a necessary component of successful collaborations. SSRL involves interdependent or collectively shared regulatory processes, beliefs, and knowledge (e.g., strategies, monitoring, evaluation, goal-setting, motivation, and metacognitive decision making), orchestrated in the service of a co-constructed shared knowledge or other shared outcome (Hadwin et al., 2011). Earlier studies have pointed out the close relationship between learners' active participation and manifestation of the regulation process during interactions (Rogat and Linnenbrink-Garcia, 2011; Grau and Whitebread, 2012; Sinha et al., 2015). However, regulation of this sort usually does not occur spontaneously, and the complexity of generating, developing, and maintaining it while collaboratively completing the task may lead to negative learning experiences, in which group members may fail both to effectively carry out the task and to interact productively in their group (Järvelä et al., 2016). More precisely, learners may fail to plan adequately, to use adaptive learning strategies, to collaborate, and to competently complete problem-solving tasks (Zimmerman and Schunk, 2011; Järvelä and Hadwin, 2013). To mitigate this problem, teachers can apply various regulatory tools to support students as they develop and strengthen their competence in group processes (Järvelä and Hadwin, 2013; Hathcock et al., 2015; Järvelä et al., 2015; Panadero and Järvelä, 2015; Van Merriënboer and Kirschner, 2017).

Effectiveness of Using Question Prompts for SSRL, PBL, and Creativity

Support is defined here as an educational technique aimed at enabling learners to accomplish tasks which otherwise might have been too challenging by, in part, making the task cognitively easier (Rosenshine and Meister, 1992; Hathcock et al., 2015). Targeted support can help promote co-construction of shared knowledge and enhance the quality of the solution ultimately reached (Barron, 2009; Belland et al., 2013; Molenaar et al., 2014).

One method of support which has been widely researched and found effective is the use of question prompts-for example, "What is the goal in this task?" or "What information do I need to find a solution to this problem?" (Xie and Bradshaw, 2008; Zheng et al., 2013; Hathcock et al., 2015). Question prompts designed by teachers can help students regulate and improve their learning when engaged in tasks by guiding them to justify their choices, explain their reasoning, evaluate their decisions, and better understand the kinds of questions which should be addressed (Xie and Bradshaw, 2008). The use of question prompts has been found to be effective in promoting self-(Michalsky, 2013) and socially shared regulation of learning (Järvelä et al., 2016), problem-solving (Ge and Land, 2003; Hmelo-Silver et al., 2007), and creativity (Zheng et al., 2013; Vincent-Lancrin et al., 2019).

As noted above, STEM studies encompass an extensive range of activities and processes, such as problem-solving and idea generation, which mutually promote and benefit from creativity (Al-Abdali and Al-Balushi, 2016; Schlatter et al., 2020). Several studies show a positive effect of training on scientific creativity. For example, in a study with 105 eleventh-grade students in China, Sun et al. (2020) showed that students' scientific creativity performance improved after training. Notably, they also found that students with high and low levels of creative potential benefited equally from the training. Sun et al. argued that creativity training can facilitate divergent thinking by making cognitive processes explicit to learners. Such findings join a large body of work pointing to the benefits of creativity in education more generally (Bryan-Kinns, 2012; Lucas et al., 2013; de Vries and Lubart, 2019; Vincent-Lancrin et al., 2019), and have led to growing interest over the past decade in research on ways to promote creative thinking in STEM education (Lucas et al., 2013; Barrett et al., 2015; Al-Abdali and Al-Balushi, 2016; Sullivan and Barbosa, 2017).

The Current Study

The current study responds to growing recognition of the links between collaboration, problem-solving, SSRL, and creative thinking in STEM education, and the potential use of support via question prompts during these processes. As mentioned above, many studies point to the advantages of supporting both collaborative work (Xie and Bradshaw, 2008; Järvelä et al., 2015, 2016) and creativity (Zheng et al., 2013; Hathcock et al., 2015) as students engage in problem-solving tasks. However, there is little understanding of how support can best be directed-whether toward SSRL, toward creativity, or toward some combination of both. Moreover, to the best of our knowledge, no study has yet examined the effects of combined support for these two aspects of problem-solving, collaboration and creativity, particularly in STEM education. Examining the two types of support separately and together can shed light on what types of support are most effective in promoting problem-solving in STEM education.

The present study aimed to compare the influence of three types of support on group members' learning regulation and scientific knowledge. One type of support was specifically designed to support the regulation of learning (SSRL), the second was specifically designed to support creative thinking, and the third comprised a combination of the two, creating three experimental groups: SSRL, Creativity, and Combined. Eight classes of students were randomly assigned to one of the three experimental groups or a control group (two classes each).

In accordance with previous studies in the field of individual self-regulation (e.g., Dignath and Büttner, 2008), our framework for all three experimental groups followed the Zimmerman (2000) cyclical model of self-regulation of learning. This model holds that interventions should aim to promote the three stages of task execution: forethought, performance, and reflection. All three experimental groups received written question prompts, along with verbal support from the students' teachers, who were trained for this purpose (see under Procedure, below). Broadly speaking, the SSRL support was based on theoretical research into collaborative regulation of learning, and in particular metacognitive awareness of cognitive, motivational, and emotional group-level regulation processes (Michalsky, 2013; Järvelä et al., 2015, 2016; Michalsky and Kramarski, 2015). The Creativity support was devised based on Torrance's (1965) three components of creativity: fluency, capturing the number of possible solution ideas generated; flexibility, capturing the number of different categories into which possible solutions fall; and originality, capturing the number of responses which are statistically infrequent. The SSRL and Creativity experimental groups each received the relevant form of support, and the Combined group received both types of support.

This study examined two outcomes: (1) the level of participation of group members in SSRL during the three stages of group problem-solving tasks, namely forethought, performance, and reflection (a qualitative measure), and (2) their scientific knowledge following completion of the tasks (a quantitative measure). The analysis was guided by the following research questions: (RQ1) How do the four study groups differ in their level of participation during the three stages of SSRL (forethought, performance, and reflection) before vs. after the intervention? (RQ2) How do the four study groups differ in their scientific knowledge before vs. after the intervention?

METHODS

Participants

The participants of this study were 104 seventh-grade students aged 12–13 from eight middle schools in Israel (51 girls, 53 boys). The schools were similar in size, with seven classes per grade. All eight schools serve populations of middle-class socio-economic status as defined by the Israel Central Bureau of Statistics (2016), and achieve average scores on Israeli national standardized tests. Eight classes, one from each of the eight different schools, were involved in a science acceleration program, in which extra school hours (90 min once a week) were allocated for science studies. Students in these classes were selected from within their grades after receiving high marks on internal tests administered by the schools. Six of these classes were randomly assigned to the three experimental groups (SSRL, Creativity, and Combined; two classes per group), while the remaining two classes served as the control group and received no support.

The eight classes together included 135 students. For the purposes of the study, each class was divided randomly into work teams, with three to four students in each team, producing 40 teams. Data for nine of these teams were dropped (four teams of four students, and five teams of three) from the analyses because of student absences during the study period. This produced a final study sample of 104 students in 31 teams (11 teams of four students, and 20 teams of three). Altogether, there were 27, 30, 23, and 24 participants in the SSRL, Creativity, Combined, and control groups respectively[1].

The study was approved by the Research Ethics Board at Bar-Ilan University, and by the Chief Scientist in the Israeli Ministry of Education (permit number 9,341). In addition, all students provided signed parental consent forms, and all teachers signed consent forms, before the start of the study.

Procedure

Before the beginning of the study, the eight teachers who ran the classes attended teacher training according to their respective treatment group. The training was conducted one-on-one and led by one of the authors of this study. All eight teachers first attended a 3-h basic training session covering (a) the importance of enhancing students' scientific creativity, (b) the problem-solving tasks that would be assigned during the study, (c) difficulties that can arise when encountering such tasks, and (d) the pedagogical content relevant to the study unit (on energy; see below). The six teachers in the three experimental groups then received extra training as appropriate. The two teachers leading the SSRL support classes received training in the rationale and techniques of the SSRL guidance method they would be implementing, as well as methods to model and introduce the subject. The two teachers leading the Creativity support classes were given an introduction to creativity comprising different definitions and approaches, techniques for teaching scientific creativity, and its connection to the curriculum and to the energy unit in particular. The two teachers who led the Combined group were trained in all topics. The extra training lasted about 3 h each for the teachers in the SSRL and Creativity groups, and 5 h for the Combined group.

In these extra training sessions, the prompts to be used during the study were presented along with the rationale behind implementing them throughout the task. Teachers were told to encourage the teams to use these prompts, and to model the use of the prompts when they introduced the tasks to their classes or when helping students. The teachers were also encouraged to initiate verbal instructions to their students—e.g., "Discuss terms in energy that appear in your solution with your teammates," or "Try to think about different ideas that your fellow teammates are raising."

Students in all eight classes spent three lessons learning a unit on energy as part of their regular syllabus. For the study, as described above, each class was divided randomly into work teams. Then, the teams were given a series of five collaborative scientific problem-solving tasks broadly based on the energy unit the students had learned prior to the study. Each task was designed to be completed in one 90-min session, with one task assigned each week[2]. The tasks were handed to the teams as worksheets. All five tasks were similar in structure, and contained

[1]The control group began with 27 participants, but three were dropped from the analyses as they did not take part in all parts of the task.

[2]Each full lesson lasted 90 min, of which about 70 min net time was available for team work (the remainder was used for organizing the class, handing out worksheets, etc.).

a problem scenario, a challenge, and a set of instructions to guide students' work on the task. A sample scenario with its associated challenge and instructions can be found in the **Appendix**.

The problem scenarios for the tasks were ill-structured, meaning that they allowed for a range of problem-solving pathways and solutions. All the scenarios were rooted in the classes' science and technology curriculum, and were designed such that the students could make use of knowledge they had learned previously (in particular in the energy unit they had learned prior to the study), but would have to build on that knowledge independently to come up with solutions. The instructions that accompanied each scenario were designed to guide students through the different stages of the task (e.g., "Come up with as many solutions as possible. Describe in detail two of your ideas," and "Describe three terms, principles, or phenomena with which you may be familiar from science class that came up in the solutions which you suggested"). The support question prompts used for the experimental groups were presented separately from these instructions (see under Intervention, below). The sample scenario in the **Appendix** shows the question prompts in speech bubbles.

The first and fifth tasks were used for pre-and post-intervention assessments. These two tasks each consisted of two parts. In the first part, the teams read the scenarios, worked through the worksheet, and came up with solutions. In the second part, each team built a model of its chosen solution from a set of materials recycled from common household goods (e.g., cardboard boxes and paper towel rolls). Both parts took place during the 90-min class, proceeding at the team's own pace. Teams were video-recorded using GoPro cameras with wide lenses and equipped with external microphones for audio enhancement.

The second, third, and fourth tasks were used for the intervention and included support for the experimental groups. These tasks included only the first part of tasks one and five described above (i.e., the teams read the scenarios, worked through the worksheet, and came up with solutions, but did not build models). In these tasks, the three experimental groups received support in the form of prompts printed on their worksheets (see under Intervention, below). The task order was shuffled between teams to prevent systematic order effects.

As described above (see under Participants), a total of 40 teams were initially video-recorded. Of these, nine teams were dropped from the analyses due to student absentees in the teams during one or more of the subsequent four tasks. Videos from the remaining 31 teams (20 h 31 min, Mduration = 40 min, Std = 3 min) were used for the micro-level analysis. The period coded and analyzed in each video was shorter than the actual duration of group work filmed, due to students moving around the class while building their models, students blocking the cameras and microphones, etc.

All students took a scientific knowledge test a week before the start of the study, and a similar test a week after the final task (see under Data analysis, below). The study procedure is summarized in **Table 1**.

Intervention

During the three intervention tasks (the second, third, and fourth tasks), the three experimental groups received support in the form of question prompts printed on their worksheets. These prompts were printed separately from the regular worksheet questions described above, and were designed to focus students' attention on the process of working collaboratively or creatively. For example, in the forethought stage the SSRL group received the question prompt "How do you plan to work cooperatively in your team?," while the Creativity group received this one: "How can you increase the number of ideas to solve the problem?" The Combined group received both sets of prompts. Prompts were included for all three stages of the process (forethought, performance, and reflection) (see **Appendix**). The study groups were also supported directly by their teachers.

Data Analysis

The effect of the intervention was assessed through two measures, qualitative and quantitative. The former addressed RQ1, and the latter addressed RQ2.

TABLE 1 | Summary of the study procedure.

Week number	Research stage	Activity			
1-2	Before experiment/study preparation	• Classes randomly assigned to study groups • Signed parental consent forms collected • Teacher training by study group • Classes divided into work teams of 3 to 4 students in each team • Pre-intervention scientific knowledge test			
3	Pre-intervention: first problem-solving task	Sessions recorded for pre-intervention SSRL analysis (no support)			
4	Intervention: second, third and fourth problem-solving tasks	SSRL support	Creativity support	Combined support	No support (control)
5					
6					
7	Post-intervention: fifth problem-solving task	Sessions recorded for post-intervention SSRL analysis (no support)			
8	After experiment/study closure	Post-intervention scientific knowledge test			

Qualitative Analysis (RQ1)

Video analysis was conducted to assess group-and individual-level participation in SSRL, using the Observer XT video analysis software platform (Noldus). Following Isohätälä et al. (2017), we used a systematic threshold of 20 s. This time threshold was used because it permitted momentary variation in participation and enhanced the uniformity of the analysis. Each segment was coded in two rounds, where the first concentrated on group interaction and the second on level of participation.

Round One: Group Interaction

The purpose of round one was to examine students' interactions within their teams. First, students' interactions were identified as either task-directed or not. Task-directed behavior could be either verbal or non-verbal (e.g., gestures and actions), as long as these were pertinent to the task. Segments in which the team was engaged in activities not pertinent to the task—e.g., playing with the microphones or camera, discussing other coursework, talking about their personal lives, etc.—were coded as "off-task." Segments were only coded as off-task if the team members engaged in non-pertinent activities for the entire 20-s segment. Segments were identified as task-directed as long as collaborative task-directed behavior was observed at least once in the 20-s segment.

Segments in which the team was seen to be working collaboratively on the task were coded based on Zimmerman's (2000) SRL theory and the cyclical model of self-regulation (Cleary and Zimmerman, 2012). Specifically, segments were coded as reflecting either forethought, performance, or reflection. These categories were mutually exclusive and could not overlap. Examples of coding based on the SRL cyclical model can be seen in **Table 2**.

The reliability of the coding was checked by double-coding the collaborative behavior of six randomly selected teams (out of the 31). Cohen's kappa values pointed to high inter-rater reliability, with $k = 0.94$ (Std = 0.05) for segments coded as off-task, $k = 0.86$ (Std = 0.40) for forethought, $k = 0.96$ (Std = 0.15) for performance, and $k = 0.89$ (Std = 0.19) for reflection.

Round Two: Level of Participation

The purpose of round two was to examine the level of participation of team members within the broader categories of forethought, performance, and reflection identified above (by definition, there was no participation in the off-task category). This was the main coding process used for the later analysis. The coding was based on previous work by Isohätälä et al. (2017), who scored level of participation using three mutually exclusive categories: active conversing, attunement, and non-responsiveness. In the present study, we coded each student's behavior throughout each 20-s segment, awarding 0–3 points depending on the student's behavior. During active conversing (three points), the student verbally contributed to the group's discussion, either by initiating turns or responding to turns. Attunement (two points) was defined as showing signs of attention through back-channeling (e.g., "uh-huh") or non-verbal reactions (e.g., laughing, leaning in, eye contact, attentive gaze on a common object of attention). Students were coded as non-responsive (one point) when they did not contribute and showed little or no signs of attunement while other members of the team worked collaboratively. In segments coded as off-task, all team members received 0 points. Each individual's scores for the full set of 20-second segments were then averaged separately for each stage (forethought, performance, and reflection) of each part of the task (the first and the second) in the pre-intervention and post-intervention assessments, thus creating twelve scores for each participant.

The reliability of the coding was checked by double-coding the participation scores from the six randomly selected teams used for the reliability checks in round one. Cohen's kappa values pointed to high inter-rater reliability, with $k = 0.91$ for segments coded as one point (Std = 0.22), $k = 0.90$ (Std = 0.07) for two points, and $k = 0.97$ (Std = 0.07) for three points.

Quantitative Analysis (RQ2)

All participants completed a pre-and post-intervention scientific knowledge test taken from the science and technology section of Israel's national standardized tests, which are approved by the head of STEM in Israel's Ministry of Education. This multiple-choice test comprised ten questions regarding energy and energy transfer (different sets of questions were used in the pre and post-tests). Analysis of variance (ANOVA) was used to examine the differences between the four study groups in scientific knowledge before and after the intervention (see under Results below).

Before addressing the research questions, we first examined whether the dependent variables were normally distributed by conducting Shapiro-Wilk tests for each study group. The dependent variables deviated significantly from normal distribution ($p < 0.05$). Therefore, we conducted both non-parametric and parametric analyses. For the former, we used the Wilcoxon test to compare the two time points for each study group, and the Kruskal-Wallis test to compare the four study groups at each time point. In what follows, we report the results for these non-parametric tests only where they differ from the results for the parametric analyses. Two-way mixed ANOVA (2 $\times$ 4) analyses with study group as a between-subjects factor and time point as a within-subject factor were conducted to examine both research questions.

RESULTS

The parametric analysis was conducted through a two-way mixed two (time: pre and post) $\times$ 4 (group: SSRL, Creativity, Combined, Control) ANOVA with group as a between-subjects factor and time as a within-subject factor. In addition, we conducted one-way ANOVAs to test for differences between the four study groups in some of the dependent variables before the intervention, and one-way ANCOVAs to test for differences between the four study groups after the intervention, while controlling for the pre-intervention measures. The results of the one-way and two-way analyses were highly similar. Therefore, in what follows we report the results only for the two-way mixed ANOVAs. In cases where the interaction of group and time was significant, we also present the results of paired samples t-tests and effect sizes (Cohen's d).

TABLE 2 | Example of data coding.

Group process	Category	Examples
Forethought	Processes activated in preparation for the learning itself. These include task analysis (goal setting and strategic planning) and self-motivational beliefs (expectations, interests, etc.).	Motivation (e.g., "We should come up with the best idea in the class"); dividing the work (e.g., "Each team member should read one question and write the group's answer"); discussing challenges (e.g., "We need to leave enough time to build the model").
Performance	Processes that occur during learning efforts. These include self-control (learning to focus on the task and use strategies to achieve goals) and self-observation (monitoring specific aspects of performance).	Praising a solution (e.g., "Wow, this is a great idea, let's develop it"); writing together (e.g., "We should write a complete answer that includes the relevant component of the question"); asking for help from the teacher (e.g., "Let's ask if the photoelectric effect means that the sun hit the panel or every light").
Reflection	Evaluating the team's behavior against the goals that were set at the beginning of the task, and making changes if necessary.	Discussing feelings aroused by the task (e.g., "Not everyone shared their ideas, maybe we should raise more ideas before continuing to build the model"); praising the group for a good session (e.g., "Our idea is very smart").

In what follows, we first report the results of the qualitative analysis (RQ1) and then the results for the quantitative analysis (RQ2).

RQ1: How do the four study groups differ in their level of participation during the three stages of SSRL (forethought, performance, and reflection) before vs. after the intervention?

As will be recalled, level of participation was scored by coding students' behavior in the video recordings described above. To test for differences between the four study groups in level of participation, we conducted two-way mixed ANOVAs with time (before and after) as a within-subject factor and group (SSRL, Creativity, Combined, control) as a between-subjects factor, comparing participation scores in the pre-intervention assessment (task one) and the post-intervention assessment (task five). In each case, we conducted separate analyses for the different stages of SSRL (forethought, performance, and reflection). In addition, as will be recalled, the first and fifth tasks each had two parts, part one and part two. We therefore conducted two separate sets of these analyses, one set for the first part of the task (see **Table 3**) and the other for the second part of the task (see **Table 4**). In what follows, we report the results for the two parts of the task separately.

First Part of the Task

As shown in **Table 3**, during the first part of the task, significant interactions of group and time were found for both the forethought and performance stages. With respect to *forethought*, paired samples *t*-tests show significant differences between the two time points in all four study groups [SSRL: $t_{(23)} = 6.85$, $p < 0.001$, $d = 1.40$; Creativity: $t_{(29)} = 2.28$, $p = 0.030$, $d = 0.42$; Combined: $t_{(22)} = 1.96$, $p = 0.050$, $d = 0.41$; and control: $t_{(26)} = 2.50$, $p = 0.019$, $d = 0.48$]. Thus, all students, regardless of their study condition, participated more during the forethought stage after completing the intervention compared with before the intervention. However, as can be seen, the effect size for this difference was significantly higher in the SSRL group compared to the other three groups.

With respect to the *performance* stage, a significant difference between the two time points was found only among students in the SSRL group, $t_{(23)} = 4.70$, $p < 0.001$, $d = 0.96$. In other words, participation during the performance stage was significantly higher after the intervention compared to before the intervention only in the SSRL group.

In the *reflection* stage, a significant main effect of time was found, indicating that participation in the reflection stage was significantly higher after the intervention ($M = 2.02$, $SD = 1.07$) compared to before the intervention ($M = 1.67$, $SD = 1.26$). No interaction was found between time and group in the reflection stage.

Second Part of the Task

As **Table 4** shows, a significant interaction of group and time was found only for the *performance* stage. Paired samples *t*-tests show a significant difference between the two time points among students in both the SSRL group and the control group, $t_{(23)} = 2.42$, $p = 0.024$, $d = 0.49$, and $t_{(23)} = 2.44$, $p = 0.023$, $d = 0.50$, respectively. However, while in the SSRL group participation in the performance stage was significantly higher after the intervention compared to before the intervention, in the control group participation in the performance stage was significantly *lower* after the intervention compared to before it.

Regarding the *forethought* stage, neither a main effect of time nor an interaction of time and group were found. By contrast, we found a significant main effect of group. Scheffe *post-hoc* analysis indicated higher participation in the forethought stage among students in both the SSRL group and the control group compared to students in the Creativity group ($p < 0.001$ and $p = 0.022$, respectively).

Regarding the *reflection* stage, no significant interaction was found in the ANOVA analysis. However, Wilcoxon tests showed a significant difference between the two time points among students in the SSRL group, $Z = 2.55$, $p = 0.011$, but not among students in the other three groups (Creativity: $Z = 1.24$, $p = 0.216$; Combined: $Z = 0.39$, $p = 0.698$; and control: $Z = 1.90$, $p = 0.064$).

RQ2: How do the four study groups differ in their scientific knowledge before vs. after the intervention?

To answer RQ2, we tested for differences between the four study groups in students' scores on scientific knowledge tests taken before and after the five study tasks. Specifically, we

TABLE 3 | Means, SD and *F*-values for participation in different stages of SSRL during the first part of the task by group and time.

	Groups	Before		After			*F*-values (η_p^2)		
		M	***SD***	***M***	***SD***	**Cohen's *d***	**Group**	**Time**	**Group × Time**
Forethought	SSRL ($n = 27$)	0.79	1.28	2.66	0.37	1.40	7.32*** (0.18)	37.95*** (0.27)	2.76* (0.08)
	Creativity ($n = 30$)	0.90	1.23	1.77	1.16	0.42			
	Combined ($n = 23$)	1.39	1.29	2.14	1.01	0.41			
	Control ($n = 27$)	0.59	1.04	1.22	1.31	0.48			
Performance	SSRL ($n = 27$)	2.36	0.37	2.67	0.18	0.96	4.24** (0.11)	1.20 (0.01)	3.87* (0.10)
	Creativity ($n = 30$)	2.33	0.35	2.23	0.46	0.22			
	Combined ($n = 23$)	2.38	0.33	2.48	0.30	0.31			
	Control ($n = 27$)	2.29	0.42	2.19	0.59	0.13			
Reflection	SSRL ($n = 27$)	1.74	1.33	2.41	0.84	0.39	1.53 (0.04)	4.86* (0.05)	0.50 (0.02)
	Creativity ($n = 30$)	1.45	1.26	1.77	1.13	0.22			
	Combined ($n = 23$)	1.75	1.25	1.84	1.21	0.06			
	Control ($n = 27$)	1.79	1.26	2.12	1.01	0.19			

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 4 | Means, SD and *F*-values for participation in different stages of SSRL during the second part of the task by group and time.

	Groups	Before		After			*F*-values (η_p^2)		
		M	***SD***	***M***	***SD***	**Cohen's *d***	**Group**	**Time**	**Group × Time**
Forethought	SSRL ($n = 27$)	2.76	0.48	2.73	0.33	0.06	11.12*** (0.26)	1.38 (0.01)	0.57 (0.02)
	Creativity ($n = 30$)	2.05	0.92	1.68	1.13	0.24			
	Combined ($n = 23$)	2.16	1.10	2.18	1.01	0.01			
	Control ($n = 24^a$)	2.45	0.60	2.26	0.57	0.23			
Performance	SSRL ($n = 27$)	2.41	0.56	2.66	0.24	0.49	3.50* (0.10)	0.09 (0.00)	4.82** (0.13)
	Creativity ($n = 30$)	2.31	0.49	2.13	0.62	0.28			
	Combined ($n = 23$)	2.35	0.50	2.47	0.41	0.25			
	Control ($n = 24^a$)	2.39	0.36	2.13	0.53	0.50			
Reflection	SSRL ($n = 27$)	1.00	1.35	2.27	1.09	0.60	3.21* (0.09)	12.48*** (0.11)	1.77 (0.05)
	Creativity ($n = 30$)	0.68	1.17	1.09	1.27	0.24			
	Combined ($n = 23$)	1.12	1.36	1.41	1.39	0.11			
	Control ($n = 24^a$)	0.83	1.23	1.40	1.18	0.48			

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$; [a]Three students in the control group did not participate in the second part of the task.

conducted two-way mixed ANOVAs with time (before and after) as a within-subject factor and group (SSRL, Creativity, Combined, control) as a between-subjects factor. The dependent variable was the students' scientific knowledge test scores.

The main effect of group was not significant, $F_{(3,100)} = 0.95$, $p = 0.420$, $\eta_p{}^2 = 0.03$. By contrast, the main effect of time was significant, $F_{(1,100)} = 51.65$, $p < 0.001$, $\eta_p{}^2 = 0.34$, indicating higher scores in the scientific knowledge test after the intervention compared to before the intervention. Finally, the two-way interaction of group and time was significant, $F_{(3,100)} = 3.75$, $p = 0.013$, $\eta_p{}^2 = 0.10$ (see **Figure 1**).

Paired samples *t*-tests revealed significant differences between the two time points in all four study groups [SSRL: $t_{(23)} = 3.09$, $p = 0.005$, $d = 0.63$; Creativity: $t_{(29)} = 6.34$, $p < 0.001$, $d = 1.16$; Combined: $t_{(22)} = 2.88$, $p = 0.009$, $d = 0.60$; and control: $t_{(26)} = 2.39$, $p = 0.024$, $d = 0.46$]. Thus, scores in the scientific knowledge test improved from the pre-to post-intervention test among all four groups. However, comparing the effect sizes shows that the improvement was significantly greater in the Creativity group compared to the other three groups.

Finally, Pearson correlation analyses were conducted to test for a relationship between students' level of participation in the SSRL stages and their scientific knowledge scores before the intervention. A significant positive correlation was found between students' pre-intervention scientific knowledge scores and their level of participation in the reflection stage of the first part of the task, $r_{(102)} = 0.30$, $p = 0.002$. In other words, students who exhibit greater scientific knowledge scores also participate more actively in reflecting about the ideas their team developed in response to the challenge outlined in the task scenario. No significant correlations were found between the students' scientific knowledge scores and their level of participation in the forethought and performance stages in the first part of the task [$r_{(102)} = 0.07$, $p = 0.449$ and $r_{(102)} = -0.01$, $p = 0.954$,

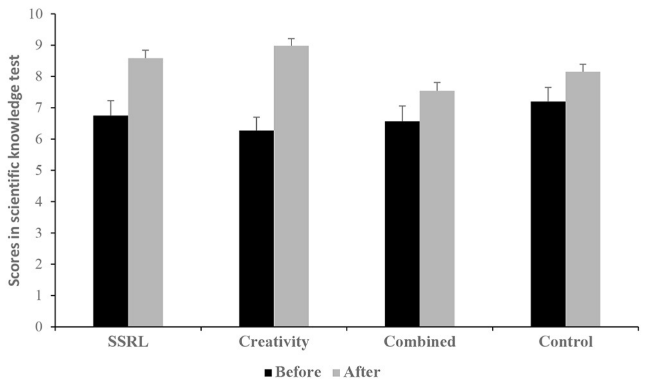

FIGURE 1 | Means (and SE) of the scores in the scientific knowledge test by group and time.

respectively]. In addition, no significant correlations were found between students' scientific knowledge scores and their level of participation in any of the stages during the second part of the task [$r_{(102)} = -0.03$, $p = 0.786$, $r_{(102)} = 0.04$, $p = 0.698$ and $r_{(102)} = 0.18$, $p = 0.074$ for the forethought, performance, and building stages, respectively].

DISCUSSION AND CONCLUSION

The Advantages of Supporting SSRL

There is extensive recognition that new methods for enhancing collaborative problem-solving are required to promote 21st-century skills. Previous studies showed the positive effects of supporting groups' regulation processes as they engage in different tasks (Järvelä and Hadwin, 2013; Järvelä et al., 2015; Järvenoja et al., 2017), and specifically in problem-solving tasks (Ge, 2001; Ge and Land, 2003; Belland et al., 2013; Liu et al., 2021). The findings of the current study likewise point to the benefits of receiving support for SSRL on the level of participation while engaging in collaborative problem-solving tasks. More specifically, we found that such a support improved the level of participation in nearly all the stages of learning regulation examined (forethought and performance in the first part of the task; forethought, performance, and reflection in the second part of the task). The other study groups displayed either lower improvement or, more often, no improvement in individuals' socially shared regulation of learning over the course of the study.

As for the differences between the groups, it could be noticed that the SSRL group improved their level of participation across the board, at all stages (from forethought in part one of the task, through performance in parts one and two, and finally reflection at the end of part two of the task). This is opposed to the control group, which showed a deterioration in their level of participation at the performing stage, the heart of the task execution. These findings are in line with previous studies showing that when support is not provided, not only does performance not improve, but negative interactions can arise within the group, threatening the collaboration needed to complete the task (Järvelä et al., 2016). Interestingly, the Combined group, which received both types of prompts, did not improve their level of participation despite receiving prompts for SSRL. Indeed, the Combined group performed substantially worse than the SSRL group despite receiving the same prompts. It may be that the combination of SSRL and Creativity prompts led to an overflow of information that did not allow participants to fully incorporate the relevant prompts into their work. That is, the high overall number of prompts for the Combined group may have been counterproductive, overwhelming participants rather than supporting them (Michalsky, 2013).

The question arises as to why support provided to the SSRL group in the current study was so effective in terms of students' participation levels relative to support for creative thinking. The prompts used in the SSRL group directly confronted the teams with different challenges and difficulties (cognitive, motivational, behavioral, etc.) that can arise during collaborative work, while also encouraging the teams to discuss the strengths and capacities of each team member. This contrasted with the Creativity group, whose support questions emphasized the creative process and not the group dynamic.

Results of previous studies have shown that SSRL is most effective when all participants of a group, rather than only some, are attuned to each other's contributions (Isohätälä et al., 2017). The current study strengthens this finding, as adding SSRL support had a positive influence on group interaction. Each team member brings his or her own learning strategies, challenges (cognitive, motivational, behavioral, etc.), and capabilities, which influence the group's dynamic and capacity to achieve its goals (Hadwin et al., 2011; Järvelä and Hadwin, 2013; Panadero and Järvelä, 2015). Moreover, shared regulation was found to be more common in groups with more active participation (Rogat and Linnenbrink-Garcia, 2011; Grau and Whitebread, 2012; Sinha et al., 2015). High levels of participation allow reciprocal exchanges, strengthening the collaborative processes which are necessary for SSRL (Iiskala et al., 2011). Ucan and Webb (2015) noted that episodes of shared regulation occurred when attentive listening happened and openness to divergent ideas was marked.

However, interestingly, while all the experimental groups displayed improvement in their scientific knowledge scores, the Creativity group improved the most. The improvement of all four groups in this measure is in line with previous studies, which showed that placing students in a problem-based learning environment—especially when they must construct their knowledge through exchanges with others—improves their academic achievement compared to traditional teaching methods (e.g., Sungur et al., 2006). For this reason, policymakers support the implementation of problem-based learning in order to promote academic achievement, both in general (OECD, 2013) and in STEM education in particular (National Research Council, 2015). Yet the fact that the Creativity group showed the highest improvement is notable. As discussed earlier, solving problems in science requires students to explore new combinations of knowledge and try a variety of routes to a solution (Hu and Adey, 2002; Hu et al., 2013)—all of which require creativity. And indeed, creativity is positively associated with both academic achievement in general (Gajda et al., 2017) and scientific knowledge (Huang et al., 2017). Thus, our findings support the notion that science education should aim to improve students' creative thinking alongside their factual scientific knowledge.

We also found a positive relationship between scientific knowledge scores in the pre-intervention test and level of participation in SSLR during the reflection stage in the first part of the task. This finding is in line with previous studies, which have also found a relationship between SSRL and knowledge co-construction (Volet et al., 2009) and between SSRL and scientific achievement (Lin et al., 2015).

The present findings suggest practical implications for STEM education programs targeting middle-school students. Empowering students' SSRL and creativity through an appropriate support framework, one that includes question prompts, has great potential to influence students' scientific knowledge growth.

In particular, the SSRL group showed improvement in different stages of the SSRL process, while the Creativity group had a significant advantage in improved scientific knowledge scores. Barron et al. (1998) and Davis (2003) point to the importance of designing support programs carefully in light of the learning objective. The different types of support tested in the current study targeted different objectives in collaborative problem-solving tasks: support directed specifically toward SSRL, support directly toward creativity and a combination of both. Thus, there is no "one size fits all" support system. Rather, educators tasked with designing a support program should ask "When to support?," "How to support?" and "Whom or what to support?" (Azevedo and Jacobson, 2008).

The current study has a number of limitations, which also offer scope for further research. First, we focused only on how support in the form of question prompts influences learning processes and scientific knowledge. Contemporary creativity research explores socio-cultural aspects of the subject, including collaborative creativity (Sawyer and Dezutter, 2009; Poutanen, 2016). Future research could examine the effects of other kinds of support interventions on teams' creative processes, as well as on individual creative thinking.

Second, the research group was comprised of seventh-grade students in science enrichment classes. To enroll in these classes, students underwent a selection process which required relatively high grades, motivation, and an interest in STEM. However, creativity and cooperation skills are important for all students. Future research should enlarge the scope of the study with a more heterogeneous population of students, including those with average STEM grades and different age groups.

Finally, the number of students, tasks and scenarios was limited. The study was conducted over seven weeks: 5 weeks of intervention and 2 weeks for pre-and post-intervention tests. Tests or observations after a significantly longer time period (e.g., 6 months post-intervention) were beyond the scope of this study. Clearly, there is a need for closer examination of how the types of support used in this study affect group dynamics and other outcomes for both individuals and groups over time, in terms of levels of participation, regulation of learning, and creative thinking processes.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was reviewed and approved by Bar-Ilan University's Institutional Review Board and Departmental Ethics Committee, in accordance with the ethical principles of the American Psychological Association. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. The ninth graders provided their assent, as required by the Chief Scientist in the Israeli Ministry of Education.

AUTHOR CONTRIBUTIONS

Both authors conceived, designed, conducted the study, analyzed the data, and wrote the manuscript.

ACKNOWLEDGMENTS

This research was part of AC's PH.D thesis, School of Education, Bar Ilan University, Israel.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.722535/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ORIGINAL RESEARCH
published: 25 November 2021
doi: 10.3389/fpsyg.2021.735127

Endorsing Sustainable Enterprises Among Promising Entrepreneurs: A Comparative Study of Factor-Driven Economy and Efficiency-Driven Economy

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Edited by:
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Specialty section:
This article was submitted to
Educational Psychology,
a section of the journal
Frontiers in Psychology

Received: 02 July 2021
Accepted: 04 October 2021
Published: 25 November 2021

Citation:
Sargani GR, Jiang Y, Zhou D,
Chandio AA, Hussain M and Khan N
(2021) Endorsing Sustainable
Enterprises Among Promising
Entrepreneurs: A Comparative Study
of Factor-Driven Economy
and Efficiency-Driven Economy.
Front. Psychol. 12:735127.
doi: 10.3389/fpsyg.2021.735127

Understanding business trails among promising aspirants may contribute to an actual motive for diminishing ecological tracks and escort to developing devotion toward deciding intentions across various entrepreneurial types and tiers solely from the sustainability domains. Therefore, this study endeavors to comprehend and seek to employ the Theory of Planned Behavior (TPB) to inspect the relationship between antecedents on sustainable enterprise intention and sustainable value creation. In this study, we used the convenience sampling method and the quantitative data of 1,070 respondents from Pakistan and China and applied a SmartPLS structural equation model and partial least square path modeling by mediational and multigroup analyses. Findings divulge that R^2 (79.8%) value in the Pakistan sample of attitudes to sustainability, perceived entrepreneurial desirability (PED), and perceived entrepreneurial feasibility (PEF) was comparatively higher than in China. The R^2 (75.6%) variance value on sustainable entrepreneurial intentions (SEI) was recorded higher in the Pakistani sample. However, the relationship of environmental values, self-efficacy, and extrinsic and intrinsic rewards show positive and significant mediational effects on both the economies of SEI. The findings disclosed an inconsistent character of extrinsic rewards, general self-efficacy, and job security depict negative significant impacts of aspirations on sustainable entrepreneurship (SE) among promising entrepreneurs on sustainability enterprises in both Pakistan and China. This study extends on existing entrepreneurship literature. Results supported the designed hypothesis and played a significant role in shedding light on an individual trait underpinning a career in a sustainable business start-up. The study looks at the issue from the viewpoint of sustainability domains. It seeks to determine the individual PED, PEF, and attitude toward sustainable entrepreneurship (ATSE) as the mediational variables. The study highlights the importance of work values in pursuing sustainability-oriented entrepreneurship programs for promising aspirants to improve their entrepreneurial skills and knowledge podium, which will encourage them to become sustainable future entrepreneurs. Furthermore, the study provides understandings for ratifying sustainable openings and debates the potential paths for sustainable business growth and opportunities among nascent entrepreneurs in both economies.

Keywords: theory of planned behavior (TPB), PLS-SEM (partial least squares structural equation model), entrepreneurial intention (EI), sustainable enterprises, sustainable development goals—SDGs, work values creation, China and Pakistan

INTRODUCTION

In the face of rising concerns about global warming, climate change, and its severe environmental effects, sustainability entrepreneurs are recognized widely as forging ahead. In many contemporary debates, sustainable businesses primarily focus on meeting basic needs while reducing human environmental footprints on product markets (Sher et al., 2020). Therefore, it is necessary to recognize the innovative practices of sustainable enterprises in sharing professional knowledge so that the fledgling entrepreneurs can improve productivity, quality, and market value, to meet the aspirations and goals of the rural society (Sargani et al., 2020). The fundamental notions of sustainable entrepreneurship (SE) and innovation ethics serve as pillars for furthering corporate solutions to address the most unrelenting social and environmental issues confronting the leading industries in the future (Sargani et al., 2020). On the contrary, sustainable enterprises provide access to inputs and information on eco-friendly management of natural resources, such as improving soil fertility, water conservation, and integrated pest management practices, thus motivating others to pursue their ideas and solutions (Sargani et al., 2020). Nevertheless, activists and academics argue that entrepreneurship can help combat climate change, reduce erosion and environmental scarcity, increase freshwater supplies and agricultural productivity, preserve biodiversity, and conserve habitats (Dean and McMullen, 2007; Ben Youssef et al., 2018). These efforts will significantly impact the developed and developing countries, boosting their sustainable economy, productivity, entrepreneurship opportunities, self-reliance, and socioeconomic stability in the long run to achieve sustainable development goals (SDGs) (Muñoz and Cohen, 2018).

Sustainable entrepreneurship, being the most diverse area of reality, has grown in popularity over the last few decades, representing the advantages, climate, social culture, and economic complexities of business solutions, and demonstrating the growth of businesses powered by function earnings (Stubbs, 2017). In the context of norms, more models and theories proposed so far are entirely driven by mature knowledge fields, especially environmental economics and social entrepreneurship (Shepherd and Patzelt, 2014; Dees, 2018). When entrepreneurship practices lead the vital notions behind SE activity, they explore business growth and economic prospects that undermine the processes of social and ecological arenas (Schaefer et al., 2015). However, this environment that promotes a balance between social, natural, and economic activities must be nurtured or restored for future generations (Parrish, 2010; Schaefer et al., 2015). As the main body of the economy, sustainable entrepreneurs are essentially full of dynamic potential, but they do not create many profits. They seek to start, adjust, and integrate these processes and activities to develop sustainable, driven, profitable economic opportunities, and carry out fundamental changes (Lans et al., 2014). Numerous scholars define sustainable entrepreneurs as individual economic representatives of an enterprise that integrate social, economic, and environmental entrepreneurial aims, and these monetary aspects should be sustainable in terms of wealth creation and business goals (Tilley and Young, 2006). Though SE has been recorded, such as in "Our Common Future," it fosters a vital understanding of this new realm of entrepreneurship that can incorporate social, environmental, and economic value creation to ensure the long-term well-being of the society with classic work as the distinct knowledge source for environmental and social entrepreneurship (Hockerts, 2017). Similarly, Shepherd and Patzelt (2014) believed that entrepreneurial activities play a significant role in maintaining ecosystems while delivering lucrative benefits (both economic and noneconomic) for entrepreneurs, stockholders, and society doing SE.

On the social level, entrepreneurship contributes to job creation and economic development (Zahra and Wright, 2016). SE, on the other hand, is crucial to achieving critical SDGs, such as public health, market innovation, industrial technology, sustainable cities, balanced production and consumption, and climate change adaptation, which all enable grassroot players to engage in community welfare and social values (Apostolopoulos et al., 2018; Perez Alonso et al., 2018). The basic types of entrepreneurship in accelerating entrepreneurship appear over time to solve the potential social problems (Rai et al., 2017; Sargani et al., 2020). Therefore, the attention of the people has been raised to recognize the intention and potential motivation of becoming such an entrepreneur among the educated youths of the future (Sargani et al., 2020).

Hence the values in SE combine the essence of social, economic, and ecological value creation in a longer time frame (Hockerts, 2015). Similarly, several scholars have suggested a connection between these principles and SE, with innovativeness and economic benefits gaining equal heft (Gibbs, 2009). In this way, some are more inclined to this type of entrepreneurship and actively believe that some entrepreneurial countries are more attractive than others, mainly because of their huge differences in structure and value preferences (Baron, 2008). However, despite the more significant development of entrepreneurship and the remarkable transformation from ancient enterprises to modern innovativeness, there is a lack of evidence to show the unique role of motivation and different values in specific forms of entrepreneurs (Liñán and Fayolle, 2015;

Sargani et al., 2020). Furthermore, there has been limited evidence of the inclination in type-specific entrepreneurial activity driving its acceptance, particularly in the case of developing nations (Liñán and Fayolle, 2015; Sargani et al., 2020).

The Y millennials/young generation and notable alumni at the universities of today, represent their strong entrepreneurial aspirations, social consciousness, and focus on youth growth, integration, and well-being; as well as the enormous potential to engage in such demanding activities without compromising their prospects (Hewlett et al., 2009; Sargani et al., 2020). Despite the rising momentum in start-ups, there is little evidence to support the entrepreneurial intention of multiple start-ups (Sargani et al., 2020). To this aim, an important and relevant issue arises: to accelerate the entrepreneurial process, educated young people are more interested in learning about the intentions and underlying motives of prospective entrepreneurs. Moreover, the youths' intentions are at the center of recognizing opportunities, and critical to understand and envisage entrepreneurial prospects; the intention to have or build a business or adapt an existing one in line with SDGs (Figge et al., 2002; Schaltegger et al., 2016). To realize scientific debates on how environmental values influence sustainable entrepreneurship (Weidinger, 2014) and which need to be based on environmental values, i.e., eco-friendly and green values (Cervelló-Royo et al., 2020).

The concept, "entrepreneurship" has emanated in the corporate world to define this most entrepreneurial and business-driven emphasis on long-term creative business solutions to support society (Schaltegger, 2018). When addressing environmental, economic, and social problems by entrepreneurial practices, the literature lacks a crucial definition of sustainable enterprise, especially in different countries, such as Pakistan and China, which face the same problem of below the average and stagnant SE (Sargani et al., 2020). To address this, policymakers in such countries have attempted to boost SE and effectively involve youths to cater to new career paths; preference perceptions and intentions must be seen as key elements in refining the sustainable entrepreneurial intentions (SEI) (Liñán and Fayolle, 2015; Rosique-Blasco et al., 2018). Pakistan and China were selected in the present study because of the differences between the two economies due to SE bottom lines. China has an emerging and efficiency-driven economy, growing more robust worldwide; However, Pakistan is factor-driven, and the developing economy faces several challenges and many setbacks (Munir et al., 2019; Sargani et al., 2020). Numerous countries, like Pakistan, benefit from the rapid economic development of China, either directly or indirectly. Both the countries collaborate in China–Pakistan Economic Corridor (CPEC) with the young millennial engagement for work and study. Given the fact that both nations collaborate in a range of fields and employ students for jobs and study, a joint knowledge of value creations and their effect on sustainable entrepreneurship (SE) may provide vital outcomes from which both countries may benefit (Munir et al., 2019; Sargani et al., 2020).

Therefore, scholarly emphasis on sustainable development is increasing rapidly, and researchers address the field from a broader perspective to encourage entrepreneurship with SE as a major driver in predicting enterprises activities (Lourenço, 2013). It is important to have entrepreneurial skills to identify opportunities that lead to sustainable growth (Hall et al., 2010). Because of this, entrepreneurs are seen as the engines of sustainable development (Shepherd and Patzelt, 2011), and their aptitude to innovate plays a key role in securing a more sustainable future. Considering the academic debate, numerous scholars assume that entrepreneurs can respond to the demands of the well-being of society (Hall et al., 2010). Due to its increasing prominence and a greater deal of attention, entrepreneurship must be originated on environmental principles to achieve sustainability practices. However, prevailing entrepreneurship intentional models ground an inquiry gap and are inept at answering the type-specific entrepreneurial research and practice from a sustainability perspective. Therefore, comparative and cross-cultural evidence has not yet been debated in these domains to predict SE behavior. In the current state of knowledge, this study explores the motives of start-up intentions among the Chinese and Pakistani aspirants in SE. As such, within the framework of the theory of planned behavior (TPB), i.e., perceived entrepreneurial desirability (PED), perceived entrepreneurial feasibility PEF, and attitude towards sustainable entrepreneurship (ATSE) and General self-efficacy (GSE), job security (JSEC), intrinsic rewards (INTR) extrinsic (EXTR) rewards, on antecedents to cater for their role through an individual's start-up intentions. In particular, this study aimed to adapt and expand current entrepreneurial intention models in a cross-country context by including work values and attitudes toward sustainable entrepreneurship.

RESEARCH BACKGROUNDS

Theoretic Context of Sustainability-Oriented Entrepreneurship

A broad frame of literature has undertaken in-depth research on an entrepreneurial motive since the inception of the theory of entrepreneurial event (TEE) (Shapero and Sokol, 1982) and TPB models resulting in the following five research themes: the primary entrepreneurial intention model, the relationship between entrepreneurial behavior and intention, the determinants of cultural, institutional, and regional levels, entrepreneurship education, and social and sustainable-oriented entrepreneurship and setting of the industry entrepreneurship education background (Liñán and Fayolle, 2015).

In the light of the study by Dentchev et al. (2018), it is noted that the advent of this trend is primarily social entrepreneurship, particularly SE. As time passes, less attention is paid to sustainable enterprises. This research has discovered a strong link between entrepreneurial intention and sustainable growth among promising students (Hockerts et al., 2018; Muñoz and Kimmitt, 2019).

Similarly, in the research by Hall et al. (2010), it was observed that the trend toward sustainability is favorably linked to emerging markets and new concepts that reduce environmental footprint. As a result of research into the role of education in the advancement of entrepreneurship, participation in the innovation process and the development of sustainable enterprises are positively linked to shared identity and self-efficacy, which may then be affected by education *via* active management and the sharing of knowledge in SE (Weidinger, 2014; Bux and van Vuuren, 2019). Moreover, results from the study of Demirel et al. (2019) showed that ecological values, such as external and intrinsic rewards, self-efficacy, and social support, are the driving forces influencing the willingness of enterprises to fascinate sustainably.

Although the substantial contribution of Shepherd and Patzelt (2014) and Sher et al. (2020) revealed SE and sustainable agribusiness development, the current investigation has intended to discover one or scarcely two planes of sustainable value creation. The study adapted from Sargani et al. (2020) introduced driving factors of SEI and attitudes toward sustainable agriculture entrepreneurship to extend the prior models into sustainability-oriented entrepreneurship.

However, when coping with the unique sense of SE, the term, value creation at work, for example, environmental and social values, can vary from the conventional term (Burnett et al., 2007). Eco-friendly entrepreneurship is focused on creating environmental value, and social entrepreneurship is closely linked to a culture that values social value creation (Cohen et al., 2019). Furthermore, economic value development has become an integral part of conventional entrepreneurship, in which entrepreneurs engage in various activities to combine multiple economic values (Liñán and Fayolle, 2015).

The investigation of Schaltegger and Wagner (2011) and (Schaltegger and Wagner, 2011; Fayolle and Gailly, 2015) showed that self-efficacy, entrepreneurial feasibility, and perceived behavior control put forward the perception phenomenon attitude of completing the same tasks and is therefore treated equally. Adapting and introducing drivers (factors) of SEI) and ATSE expand the previous TPB model into sustainability-driven entrepreneurship. As a result, constructions on environment value, intrinsic reward, ATS, and SEI explicitly incorporate social and environmental value creation dimensions (**Figure 1**). By adding these variables, the present model includes ecological and social value creation. In contrast, PEF and PED are implicit reflections of economic value creation. Supplemented by general self-efficacy, PEF, and perceived behavioral control have all been linked to consider the driving factors of the SEI phenomenon.

Sustainability-Oriented Entrepreneurship Proxies

As previously mentioned, two of the points in favor of SE include supplying youth with a diverse range of job options and identifying and evaluating opportunities (Shepherd and Patzelt, 2014; Hanohov and Baldacchino, 2018). As the findings of Koe and Majid (2014) showed, the youth seek the adequacy of their perceived feasible knowledge, abilities, and skills and their perceived desire to pursue specific opportunities for possible career choices (Fitzsimmons and Douglas, 2011). The PEF, which refers to the belief range of individuals, possesses the knowledge, ability, and skills needed to become entrepreneurs or perform challenging tasks; that is, PED indicates how specific entrepreneurial careers are attractive. Simultaneously, prior empirical literature points out that SEI has a positive relationship with the early stage of TPB, such as ATSE, PEF, and PED (Liñán and Santos, 2007; Guerrero et al., 2008; Sher et al., 2020).

Self-Efficacy and Work Values of Individuals in Sustainable Entrepreneurship

Since job values reflect work success and inspiration, they provide a different way to support, inspire, propel, and foster individual entrepreneurial activity. This propensity is closely linked to the attitude of the former toward a specific profession (Kirkley, 2016). It is worth noting that the work values consider the obvious and not apparent results that a person can achieve by pursuing a job or a business undertaking (Swaney et al., 2012). These perceived work goals and work choices are formed by work values called external and internal rewards (Vansteenkiste and Ryan, 2013). Therefore, an external reward of a person refers to the attraction of the person to personal interests. This kind of value pursues a job to obtain more power, prestige, money, reward, and status (Antonioli et al., 2016).

On the contrary, intrinsic rewards describe learning, innovation orientation, and problem-solving behaviors, encouraging individuals to seek innovative skills, new opportunities, and solve challenging problems (Twenge et al., 2012; Sargani et al., 2019). At present, the research on social entrepreneurship has taken environmental value and job security as the other two work values (Fukukawa et al., 2007; Twenge et al., 2012). Environmental values describe the altruistic behavior of a person (e.g., universalism, compassion, and altruism), which leads to caring for individuals, the surrounding environment, and other individuals in the society with enthusiasm and passion (Lyons et al., 2010). Also, unlike environmental values, safety defines personal preferences for security, stability, and harmony in the workplace (Twenge et al., 2012). According to Patzelt and Shepherd (2016), entrepreneurial career choice is positively related to risk-taking and negatively related to work safety. Likewise, in the studies by Barbosa et al. (2007) and Monteiro et al. (2019), individuals with higher entrepreneurial career choices tend to value security less and are more independent and risk-takers. Therefore, both external and internal rewards are positive, while a sense of security is negatively correlated with higher entrepreneurial intention and has a direct positive correlation with internal reward and SEI. However, this study scrutinizes the role of four fundamental work values (environmental values, sense of security, external, and internal rewards), because these values are highly related to different forms and levels of entrepreneurship and different forms of value creation. Hence ecological values and intrinsic rewards are positively correlated with environmental and social value creation, while the external reward is positively correlated with economic value creation.

In essence, work values are an essential link for individuals to choose work through attitude and motivation (Swaney et al., 2012). Precisely, driving forces and values guide individuals to

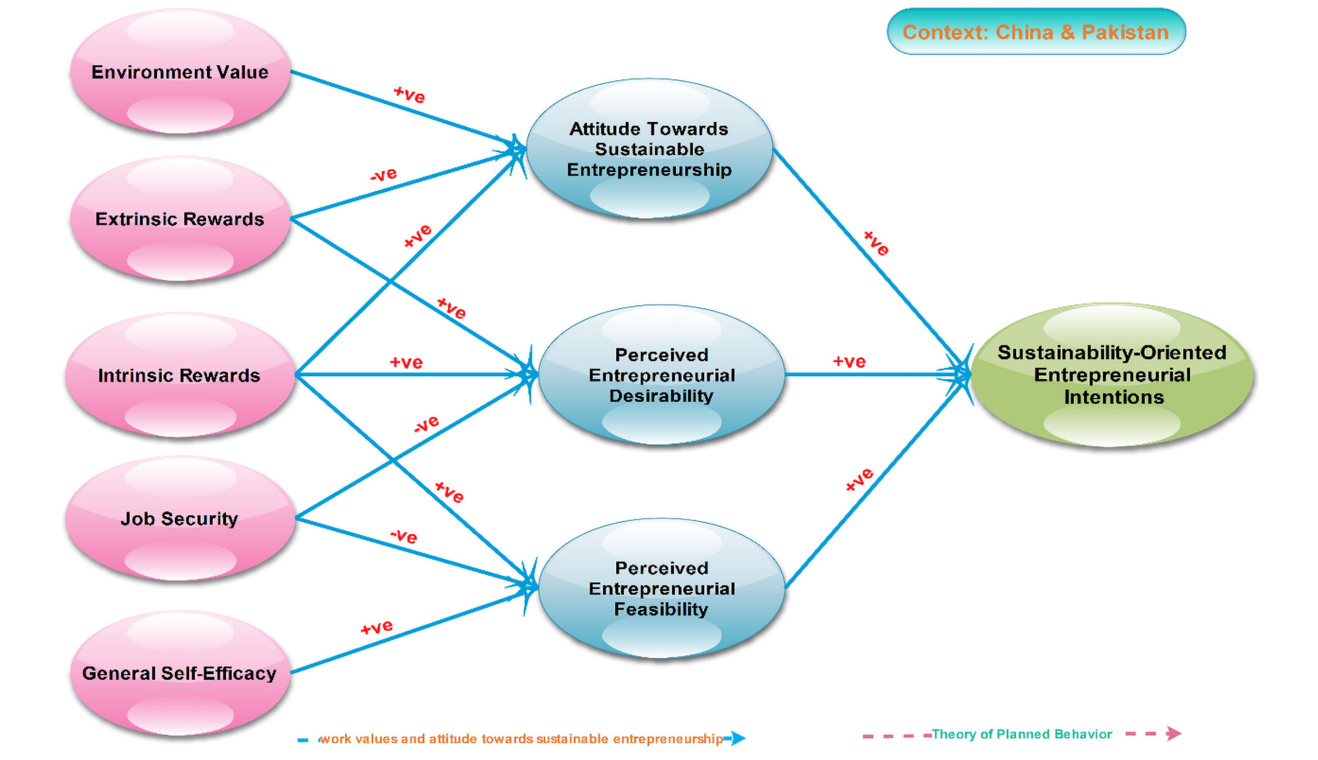

FIGURE 1 | The research framework of the study based on hypothesized constructs adopted form Sher et al. (2020) and Vuorio et al. (2018).

choose a particular form of the decision-making process. The decision to engage in a particular job or work to become an entrepreneur is more likely to be different from others and may take numerous methods (Jaén and Liñán, 2013). Since work values guide the process of opportunity identification and evaluation through ideal behaviors and goals, there is a clear link between the attractiveness of specific entrepreneurial choices, individual PED, and work values (Esfandiar et al., 2019). Whereas the main motive of pursuing external value is the monetary benefit, prestige, and status, the extrinsic reward is positively related to SEI) and PED (Choo and Wong, 2006; Antonioli et al., 2016). Therefore, if adequately followed, SE also offers higher income, social status, and esteem (York and Venkataraman, 2010; Schaltegger and Wagner, 2011; Sher et al., 2020). Based on the given literature on work values viz-á-viz innovativeness, wealth and power creation, and entrepreneurial pledge and attention, the following relationships are established between the studied work values, such as extrinsic reward, intrinsic reward, and job security with PED and SEI.

Similarly, environmental importance is closely linked to a positive mindset and plays a critical role in advancing SE and shaping and driving focus of an individual on the workable value of social and ecological facets of creation in search of various opportunities (Weisgram et al., 2011; Swaney et al., 2012). Current studies have mainly focused on two facets of value creation: environmental and economic (Dean and McMullen, 2007; Hanohov and Baldacchino, 2018; Domurath and Patzelt, 2019) and generally lack social value creation in SEI, even though social value creation is critical to the appetite of an individual for social entrepreneurship (Wilson and Post, 2013). In comparison, environmental importance and intrinsic reward are the motivators for people to solve social issues.

Sustainable entrepreneurship connects the environmental, economic, and social values (Cohen et al., 2019; Douglas et al., 2020), whereas intrinsic rewards, conjointly with prosocial motivations, play significant uprightness in creating, recognizing, evaluating, and exploiting business opportunities with environmental and societal problems (Shepherd, 2015). Furthermore, the study indicates that environmental importance increases the probability of sighted opportunities by altruistic actions (e.g., altruism and empathy) and PED in ecological and social entrepreneurship (Shepherd and Patzelt, 2014; Sher et al., 2020).

Conferring to a study by Hockerts (2015), SE is solely focused on identifying entrepreneurial opportunities that restore the disequilibria caused by a disparity of the usage of natural resources by converting industries into more socially and environmentally acceptable norms. Though the study Sargani et al. (2020) revealed that SE provides triple value creation, combining disparate values to generate economic value will clash with goals for creating environmental and social values. Extrinsic rewards, in particular, fuel entrepreneurship; the literature indicates that a preference for norms and authority is negatively linked to environmental attitudes (Fukukawa et al., 2007; Twenge et al., 2012). Thus, ATSE has a negative relationship between extrinsic reward and SEI, while intrinsic reward positively correlates with SEI. According to the literature (Muñoz and Cohen, 2018), since environmental and social challenges are complex, the existing structural strategies frequently seem unrealistic. Nevertheless, these uncertainties, socioeconomic difficulties, and social capital building can be overcome by ingenuity and proactive ATSE (Shukla, 2021), which is confirmed by the study and theoretical basis on the relationship among external rewards, intrinsic reward, and ATSE with SEI.

Likewise, great arguments relate to entrepreneurial career choice with sovereign innovativeness risk-taking (Hessels et al., 2008; Bolton, 2012). As a result, it is proposed that a presumed entrepreneurial interest corresponds to the recognition of an individual with regard to a particular entrepreneurial performance. The livelihood of the choice of a person appears to enable him to pursue the following personal ideals linked to the apparent accomplishments of the profession (Segal et al., 2005). Furthermore, a previous study has shown that human risk-taking, independence, individuality, and creativity are linked to entrepreneurial career engagement (Hessels et al., 2008). Since risk-taking is a prerequisite for entrepreneurs to consider, autonomy and creativity are directly linked to an entrepreneurial profession. Job security seems to be negatively associated with PEF and SEI. This reveals that PEF is associated with work security and internal compensation and that internal reward is connected to SEI.

On the other hand, individual self-efficacy is described as a vision capacity applied to various entrepreneurial contexts. It is related to the degree of self-efficacy (Zimmerman, 2000). When looking for demanding tasks, people with higher self-efficacy are more likely to prefer self-employment (Pihie, 2009; Piperopoulos and Dimov, 2015). Similarly, confident people with their abilities, talents, and competence level stick to a single company, which decides whether the business succeeds or fails (Hechavarria et al., 2012). Self-efficacy and personal PEF are inextricably linked. PEF shows a degree of confidence in the people so that they can begin and complete a particular task (Krueger et al., 2000; Fitzsimmons and Douglas, 2011). According to research, it is found that individuals with higher self-efficacy are more confident in their ability to achieve their goals. As a result, self-efficacy is linked to being an entrepreneur and the likelihood of being a profitable entrepreneur (Arrighetti et al., 2016). The study by Smith and Woodworth (2012) revealed the critical mechanism of forming the intention to uphold social value entrepreneurship and shows a connection between self-efficacy and SE.

In the light of the above theoretical mechanism and pieces of evidence, the following hypotheses are designed for the current study:

Research Hypotheses

H1. Attitude toward SE will positively mediate the relationship between environment value and SEI among Chinese as well as Pakistani aspirants.

H2. Attitude toward SE will positively mediate the relationship between intrinsic reward and SEI among Chinese as well as Pakistani aspirants.

H3. Attitude toward SE will negatively mediate the relationship between extrinsic reward and sustainability-driven entrepreneurial intentions among Chinese as well as Pakistani aspirants.

H4. Perceived entrepreneurial desirability will positively mediate the relationship between extrinsic reward and SEI among Chinese as well as Pakistani aspirants.

H5. Perceived entrepreneurial desirability will positively mediate the relationship between intrinsic reward and SEI among Chinese as well as Pakistani aspirants.

H6. Perceived entrepreneurial desirability will negatively mediate the relationship between job security and SEI among Chinese as well as Pakistani aspirants.

H7. Perceived entrepreneurial feasibility will positively mediate the relationship between intrinsic reward and SEI among Chinese as well as Pakistani aspirants.

H8. Perceived entrepreneurial feasibility will negatively mediate the relationship between job security and SEI among Chinese as well as Pakistani aspirants.

H9. Perceived entrepreneurial feasibility will positively mediate the relationship between self-efficacy and SEI among Chinese as well as Pakistani aspirants.

H10. The impact of (a) [environment value (ENV), intrinsic reward (INTR), extrinsic reward (EXTR), job security (JSEC), and general self-efficacy (GSE)] on TPBs indicators (ATSE, PED, and PEF) and (b) the extents of TPB on SEI will likely be different between the two countries (i.e., China and Pakistan).

METHODOLOGICAL APPROACH

Data Sources and Measurements

According to a study by Pizzi et al. (2020), currently, the highest proportion of youth bulge is significantly affecting the structure of the global economy in the coming years and catalyzes the achievement if properly educated and used the SDGs. Thus, data from the Efficiency-Driven Economy (China) and factor-driven economy (Pakistan) using a quantitative design *via* an anonymous questionnaire were randomly selected from eight universities out of four university participants enrolled from China and four from Pakistan.

The Consent and Ethical Consideration of the Participants

Personal ethics are an important challenge for social scientists, and the human rights of the interviewers must be respected by advice and guidelines on survey instruments and considerations, such as securing permission and protecting anonymity and confidentiality. As a result, all qualified survey respondents were told about the intent of the study, the right to participate willingly, and the right to withdraw at any time, without explanation before data collection. Respondents were told that the information gathered will be kept private and that the research will be conducted solely for scholarly purposes. The consent form is included in the scale of the survey plan in written form. In the process of quantitative data collection, the researchers shared the purpose and objectives of the study with the participants in two languages (Chinese and English). At the same time, it was approved by the research ethics committee (School of Economics, Sichuan Agricultural University, Chengdu).

The development of constructs was driven by critical observations from previous literature, supplemented by expert opinions. A two-step procedure validated the appropriateness and logic of the constructs until performing an individual field survey. First, to ensure relevant evidence and back-projected frameworks of technological terminology, more than three field experts, tested the constructs, working on sustainability attitude, sustainable business growth, TPB, and job values. Next, to finalize the actual data collection questionnaire, the pretesting questionnaire was done on 50 students from six different universities. Then, the questionnaire, study title, research goals, demographic details about the subjects, and statements on a 5-point Likert scale (1-extremely not important/disagree, 5-extremely important/agree) were presented, accompanied by various reflecting mechanisms on the entrepreneurial intentions of the students to elicit required responses.

Finally, this research used a cross-sectional survey design to gather data; thus it was essential to investigate the existence of common method variation (CMV) to increase the effectiveness of the interviewee details (Podsakoff et al., 2012). Herman's one-way test was used to study the CMV. According to the results of principal component analysis, the first factor explained 78.3% of the total variation. The first factor in the data can only explain 61.4% of the difference. Hence, CMV was not an issue in the current research. Furthermore, the new technique of complete collinearity proposed by Kock (2015) was used to identify the possibility of CMV scenarios. According to Kock, when the variance inflation factor (VIF) values for all constructs in the structural model are less than 3.3, it indicates that there is no collinearity. The VIF values of all constructs in this study varied between 1 and 2.843, suggesting a lack of collinearity.

Demographic Profiles of the Participants

A total of 1,070 respondents were surveyed, and the data were gathered by handing out questionnaires and asking them to fill them out. The 15 primary agricultural disciplines offered by the universities in China and Pakistan were chosen. These courses and subjects are essential contributors to global SE; so students from these courses and subjects were chosen (Knudson et al., 2004; Wadhwa et al., 2011). As for the study of young people, the age of the respondents was limited to between > 21 and < 50. More importantly, the sampling framework includes graduate students in the respective final semesters/years of their degree programs.

The demographic evidence of the profiles of the Chinese and Pakistani respondents reveals that 48.4/55.8% were men and 51.6/44.2% were women participants, respectively. The majority of the respondents were 50.1% ($n = 262$) between 21 and 30 years of age. Predominantly, 51.7/53.3% of the students were pursuing their bachelor's degrees and 45.3/42.8% were studying for master's degrees, respectively. About 51.6/51.1% has shown less than 1 year of agribusiness experience. Regarding the understanding of agriculture work, 64.7/65.0% of respondents showed less than 1 year. Finally, 52.7/52.6% were inclined to have training in farming, and 47.3/47.4%, did not show any training exposure in farming with regard to entrepreneurship. Further detail of the control variables is given in **Table 1**.

Study Measurement Scales

Firstly, this study uses the entrepreneurial intention scale provided by Liñán and Chen (2009). This structure measures key entrepreneurial intentions because these intentions best describe the entrepreneurial aspirations or the desire to own a business. Next, according to the research results scale, PED was used (Liñán and Chen, 2009); the measurement of PEF is based on the study by Krueger (1993). The scale for measuring work values builds on insights adopted from many studies (Peterman and Kennedy, 2003; Twenge et al., 2012). The scale contains the work values of four factors, namely: (1) environmental values, (2) job security, (3) intrinsic rewards, and (4) extrinsic rewards. Finally, the scale for general self-efficacy was built by taking valuable insights from the study by Gibbs (2009). This scale examined the perceived competency level of an individual by which she/he is motivated to start and pursue a business successfully.

Finally, in measuring entrepreneurial opportunity attributes, according to the specific types of entrepreneurship, the attitudes of the students toward SE and entrepreneurial goals are ranked, which provides a reasonable measurement method for SEI. In this regard, Osgood's semantic differential scales, in essence, serve as essential measurement scales (Kriyantono, 2017). According to the choice of the respondents, the pairings with opposite characteristics in the ideal entrepreneurship were evaluated. More importantly, these characteristics pay more attention to the society and the environment and reflect SE. They think about the most vulnerable individuals in the society, global poverty, environmental issues, sustainable development, responsible use of natural resources, and maximization of social benefits, and not economic progress. The second indicator to measure the attitude toward SE requires respondents to consider the environmental and social impacts when assessing entrepreneurial opportunities. Therefore, all of these projects are based on SDGs to help understand the sustainable development intentions of youth in fostering sustainable enterprises (Org et al., 2018).

Validity of Measurements

The validity of the scale was assessed using average variance extraction (AVE) in this analysis. The convergence efficiency is confirmed because the AVE value in this analysis is equal to or higher than 0.5, which is the threshold degree (Hair et al., 2012; Leguina, 2015). Furthermore, discriminant validity and the used heterotrait-monotrait (HTMT) criterion confirmed by measuring the association between the structures show that the approximate magnitude of discriminant validity of the inter-structure correction is less than the square of the average threshold (Henseler et al., 2016). As a result, these measurements imply that the framework is significant if the statistical analyses are necessary to arrive at a modest effects of composite reliability and cronbach's alpha **Table 2**.

Data Scrutiny and Analysis

SmartPLS 3.0 software is used to analyze the results. The PLS is a second-generation multivariate analysis approach based on

TABLE 1 | Demographic profiles of aspirant entrepreneurs from China vs. Pakistan.

Group		China *N* = 547		Pakistan *N* = 523		Total *N* = 1070	
	Frequency		% age	Frequency	% age	Frequency	% age
Gender	Male	265	48.4	292	55.8	557	52.1
	Female	282	51.6	231	44.2	513	47.9
	Total	547	100	523	100	1070	100
Age (years)	<21	43	7.9	41	7.8	84	7.9
	21–30	269	49.2	262	50.1	531	49.6
	31–40	181	33.1	162	31	343	32.1
	41–50	52	9.5	56	10.7	108	10.1
	>50	2	0.4	2.0	0.4	4	0.4
	Total	547	100	523	100	1070	100
Experience in agriculture	<1	354	64.7	340	65	694	64.9
	4-Jan	63	11.5	55	10.5	118	11.0
	10-May	54	9.9	52	9.9	106	9.9
	15-Nov	39	7.1	36	6.9	75	7.0
	> 15	37	6.8	40	7.6	77	7.2
	Total	547	100	523	100	1070	100
Experience in agribusiness	<1	282	51.6	267	51.1	549	51.3
	4-Jan	67	12.2	65	12.4	132	12.3
	10-May	70	12.8	67	12.8	137	12.8
	15-Nov	71	13	67	12.8	138	12.9
	>15	57	10.4	57	10.9	114	10.7
	Total	547	100	523	100	1070	100
Average monthly Income	<10,000	111	20.3	103	19.7	214	20
	10,000–15,000	272	49.7	264	50.5	536	50.1
	16,000–20,000	87	15.9	80	15.3	167	15.6
	21,000–25,000	58	10.6	57	10.9	115	10.7
	>25,000	19	3.5	19	3.6	38	3.6
	Total	547	100	523	100	1070	100
Level of education (degree)	Under graduate	283	51.7	279	53.3	562	52.5
	Master graduate	248	45.3	224	42.8	472	44.1
	Doctoral graduate	16	2.9	20	3.8	36	3.4
	Total	547	100	523	100	1070	100

TABLE 2 | Construct reliability and validity of China vs. Pakistan.

Construct	Total Sample				China				Pakistan			
	α	rho_A	CR	AVE	α	rho_A	CR	AVE	α	rho_A	CR	AVE
ATSE	0.81	0.82	0.87	0.57	0.81	0.83	0.87	0.58	0.79	0.80	0.86	0.55
ENV	0.84	0.85	0.89	0.68	0.85	0.86	0.90	0.69	0.81	0.81	0.87	0.64
EXTR	0.81	0.84	0.86	0.56	0.81	0.84	0.86	0.56	0.81	0.85	0.87	0.58
GSE	0.80	0.81	0.87	0.63	0.77	0.79	0.85	0.59	0.82	0.83	0.88	0.66
INTR	0.86	0.86	0.90	0.64	0.86	0.86	0.90	0.63	0.86	0.86	0.90	0.65
JSEC	0.75	0.77	0.84	0.57	0.74	0.76	0.84	0.57	0.74	0.77	0.83	0.56
PED	0.65	0.68	0.79	0.50	0.65	0.70	0.79	0.50	0.61	0.62	0.77	0.46
PEF	0.74	0.75	0.83	0.49	0.69	0.73	0.80	0.45	0.77	0.78	0.85	0.53
SEI	0.89	0.90	0.92	0.70	0.89	0.90	0.92	0.69	0.89	0.89	0.92	0.69

α, Cronbach's Alpha; (rho_A) Reliability Coefficient CR, Composite Reliability; AVE, Average variance extracted.

structural equations that eliminate the distribution hypothesis and have high statistical potential even for small sample research (Ringle et al., 2020). The validity of the elements used in the system can be conveniently checked using partial least squares by simplifying and validating the procedure before establishing the final structure model in each manifest variable (MV).

TABLE 3 | Measurements of the model-fit-structural index.

The goodness of fit measures	Estimated model	Total	China	Pakistan
SRMR	<0.08	0.07	0.07	0.06
d_ULS	<95%	95%	95%	95%
d_G	<95%	95%	95%	95%
Chi-Square	8412.67	7843.51	4298.52	5080.47
NFI	>0.90	0.95	0.93	0.94

Hu and Bentler (1998).

TABLE 4 | Measurement model factor loadings of China vs. Pakistan.

Constructs	Items	Total Sample		China		Pakistan	
		Loadings	VIF	Loadings	VIF	Loadings	VIF
ATSE	ATSE1	0.77	1.67	0.81	1.86	0.69	1.40
	ATSE2	0.79	1.83	0.80	1.93	0.73	1.64
	ATSE3	0.78	1.67	0.77	1.63	0.77	1.70
	ATSE4	0.67	1.40	0.61	1.31	0.75	1.55
	ATSE5	0.78	1.59	0.78	1.62	0.75	1.49
ENV	ENV1	0.86	2.14	0.86	2.22	0.85	1.88
	ENV2	0.83	1.91	0.84	1.96	0.80	1.74
	ENV3	0.77	1.62	0.76	1.68	0.74	1.44
	ENV5	0.83	1.88	0.84	1.95	0.80	1.68
EXTR	EXTR1	0.82	2.66	0.80	2.54	0.87	2.05
	EXTR2	0.85	2.90	0.84	2.95	0.87	2.84
	EXTR3	0.82	2.16	0.80	2.11	0.86	2.43
	EXTR4	0.69	1.22	0.70	1.19	0.67	1.35
	EXTR5	0.53	1.25	0.58	1.30	0.47	1.22
GSE	GSE1	0.79	1.57	0.78	1.52	0.78	1.58
	GSE2	0.67	1.30	0.62	1.22	0.74	1.43
	GSE3	0.83	2.04	0.81	1.79	0.86	2.51
	GSE4	0.86	2.18	0.85	1.96	0.86	2.54
INTR	INTR1	0.81	2.33	0.80	2.09	0.85	2.97
	INTR2	0.78	2.22	0.77	2.05	0.81	2.70
	INTR3	0.86	2.66	0.84	2.37	0.89	2.52
	INTR4	0.73	1.63	0.74	1.73	0.70	1.49
	INTR5	0.81	1.94	0.83	2.18	0.75	1.62
JSEC	JSEC1	0.80	1.57	0.79	1.54	0.81	1.55
	JSEC2	0.72	1.41	0.75	1.47	0.64	1.27
	JSEC3	0.68	1.29	0.66	1.25	0.69	1.32
	JSEC4	0.82	1.53	0.80	1.49	0.83	1.54
PED	PED1	0.70	1.33	0.67	1.37	0.71	1.23
	PED2	0.79	1.58	0.83	1.85	0.70	1.26
	PED3	0.49	1.09	0.44	1.06	0.58	1.13
	PED4	0.79	1.41	0.82	1.55	0.72	1.24
PEF	PEF1	0.80	1.61	0.83	1.63	0.76	1.56
	PEF2	0.70	1.36	0.70	1.33	0.69	1.40
	PEF3	0.72	1.44	0.71	1.40	0.74	1.47
	PEF4	0.60	1.22	0.44	1.12	0.73	1.44
	PEF5	0.66	1.28	0.62	1.22	0.70	1.41
SEI	SEI1	0.88	2.84	0.89	2.86	0.86	2.68
	SEI2	0.89	3.33	0.87	2.89	0.91	2.56
	SEI3	0.88	3.24	0.87	2.89	0.89	2.16
	SEI4	0.75	1.70	0.77	1.77	0.75	1.63
	SEI5	0.76	1.70	0.76	1.74	0.74	1.56

For this purpose, the following parameters of a given tangent point are observed to test the quality and reliability of the structure used: (a) manifest variable loading (MV) > 0.50; (b) AVE > 0.5; (c) items per construct reliability > 0.5; and (d) Cronbach's Alpha (A) > 0.70 (Henseler et al., 2016; Ringle et al., 2020). Also, the Breusch Pagan test is used to test the heteroscedasticity of the observation and confirm that there are no heteroscedasticity data results.

STUDY RESULTS

Model Measurement Index

Model fit indices were used to verify the overall fit index of the model before checking the analysis hypotheses. Consequently, all the values of the indices for the final proposed model indicated a good match due to the PLS results of the three models (full, and split), and were evaluated using standardized root mean square residual (SRMR) (Hu and Bentler, 1998). An SRMR score less than 0.08 suggests an adequate match. The SRMR value for the entire model was 0.07 for the Chinese group and 0.06 for the Pakistani group, all of which were less than the required threshold of 0.08, suggesting a satisfactory match between the empirical and theoretical covariance matrices indicated by the models. The findings of predictive indices are shown in **Table 3**.

The partial least squares structural equation modeling (PLS-SEM) analysis considered the relationship value and significance level, and the variance (R^2) was explained (Henseler et al., 2016). To test the hypotheses of H1–H9, bootstrapping was used in 5,000 re-samples of each country, such as China and Pakistan. This provides the knowledge of the importance of the predictable relationships between sustainability-driven indicators, like ENV, EXTR; INTR; GSE; and JSEC, on the dimensions of TPB and SEIs. The results for the significance of each anticipated constructs factor loadings are shown in **Table 4** and **Figure 2**. The total variance of the two countries is R^2 = 78.3%. Moreover, for the sample of Chinese students, R^2 explained 75.6% of the variance in SEIs. However, there are three antecedents (ATSE = 66.1%, PED = 57.5 %, and PEF = 69.9%). Overall, the Pakistani student sample, R^2 = 79.8% of the variances in SEIs and the three dimensions (ATSE = 70.2 %, PED = 59.1%, and PEF = 73.1%) are explained.

In both countries, all three TPB mediational aspects reveal a positive significance level for explaining SEI. The primary goal of the study is to determine the gaps between the subsamples of the two countries. There are essential variations in the variation described by the entire model alone or together between the two countries studied. As a result, the variance R^2 value of the TPB in the study of Pakistani graduates is higher than in the model of Chinese graduates, indicating that TPB is more predictive power in the developing country than in the emerging economy. As a result, graduates from the developing-country have a more optimistic perspective on becoming sustainable entrepreneurs than scholars from an emerging country.

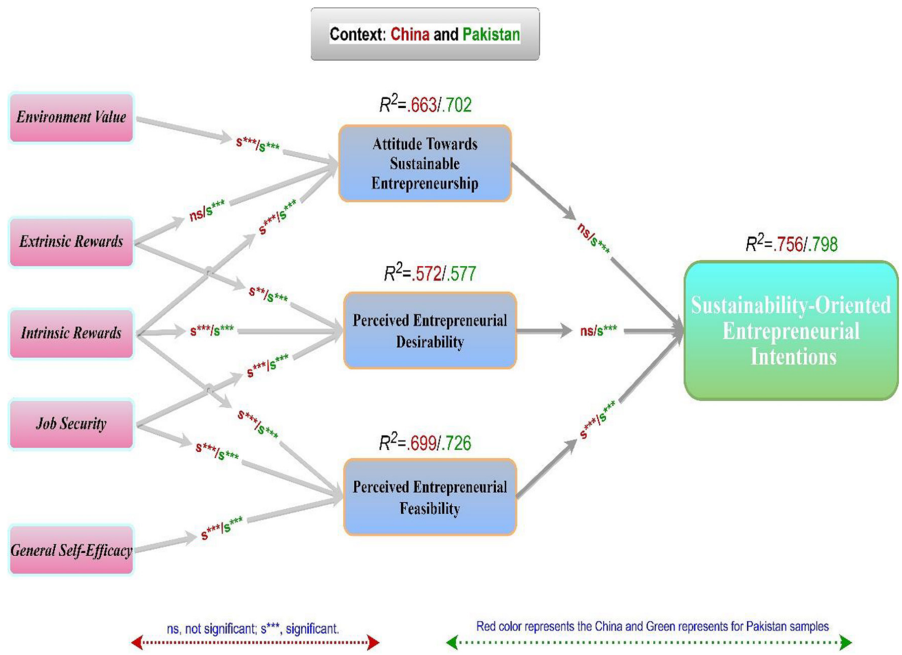

FIGURE 2 | Results of the structural model linking work values and TPB to SEI.

Convergent Validity

This study examined the convergence validity of all the constructs using a benchmark test. Model discriminant validity which indicates the extent to which each construct possesses a unique attribute that makes it different from others in the conceptual model was assessed by a two-step approach. The first approach (the Fornell–Larcker criteria) included comparing the square root of AVE for each latent variable with the correlation of other constructs in the model. The second approach (HTMT) included measuring the ratio of construct correlations to within construct correlations (Henseler et al., 2016). **Tables 5**, **6** determine that the discriminant validity for the full and split dataset is established. Particularly, the diagonal values (**Table 5**) for all the constructs are greater than other values, which are provided in rows and columns (Fornell and Larcker, 1981) and HTMT values (**Table 6**) for all the constructs are less than 0.90 in HTMT (Voorhees et al., 2016).

Hypotheses Testing in Structural Model

To assess the proposed relationships (direct and indirect) between structures based on the structural model, PLS-SEM was used. The results that demonstrate explicitly significant positive associations, represented in **Figure 2**, are as follows: First, aligned with TPB, the results show that ATSE entirely drives SEI, PED, and PEF of the aspirants. Therefore, the results fully support the direct relationship between these three mediators (ATSE, PED, and PEF) and SEI. These findings are consistent with the previous study by Urban (2019) and strengthen the understanding that SEI is more complex than linear connection.

The study outcomes exemplify that extrinsic rewards and intrinsic rewards revealed a direct and positive PED impact. In contrast, job security has an inverse effect on it in the samples of both countries. Therefore, these outcomes align with the existing literature on individual entrepreneurial intentions

TABLE 5 | Discriminant validity of the total sample (Fronell–Larcker criterion).

Constructs	ATSE	ENV	EXTR	GSE	INTR	JSEC	PED	PEF	SEI
ATSE	***0.76***								
ENV	0.73	***0.82***							
EXTR	0.47	0.42	***0.75***						
GSE	0.71	0.79	0.52	***0.79***					
INTR	0.75	0.81	0.57	0.78	***0.80***				
JSEC	0.78	0.73	0.50	0.76	0.74	***0.76***			
PED	0.68	0.73	0.42	0.68	0.68	0.73	***0.71***		
PEF	0.75	0.77	0.51	0.78	0.80	0.78	0.71	***0.70***	
SEI	0.78	0.83	0.54	0.81	0.87	0.77	0.70	0.81	***0.84***

Diagonal bolded and Italic values show the square root of AVE.

TABLE 6 | Discriminant validity of the total sample (HTMT 0.90 Criteria).

Constructs	ATSE	ENV	EXTR	GSE	INTR	JSEC	PED	PEF	SEI
ATSE									
ENV	0.87								
EXTR	1.00	0.94							
GSE	0.94	0.99	1.06						
INTR	0.92	0.97	0.99	1.00					
JSEC	0.60	0.65	0.66	0.68	0.71				
PED	0.81	0.78	0.80	0.77	0.82	0.83			
PEF	0.89	0.95	0.94	0.95	0.97	0.62	0.80		
SEI	0.90	0.93	0.93	0.92	0.95	0.70	0.85	0.98	

TABLE 7 | Outcomes of direct effects of path coefficients among the constructs.

Paths	Total sample		China		Pakistan	
	β-coefficient	*t*-values	β-coefficient	*t*-values	β-coefficient	*t*-values
ATSE - > SEI	0.34	12.84	0.32	9.68	0.36	8.71
PED - > SEI	0.14	5.03	0.12	3.55	0.19	4.79
PEF - > SEI	0.46	15.29	0.51	13.27	0.37	7.78
ENV - > ATSE	0.38	9.34	0.36	6.84	0.37	6.34
EXTR - > ATSE	0.08	3.08	0.06	1.73	0.15	4.14
INTR - > ATSE	0.40	9.51	0.42	7.73	0.38	6.87
EXTR - > PED	–0.01	0.38	–0.08	2.24	0.17	4.62
INTR - > PED	0.31	8.08	0.36	6.82	0.19	4.64
JSEC - > PED	0.50	14.05	0.45	8.85	0.54	13.08
INTR - > PEF	0.37	13.37	0.44	10.31	0.32	8.57
GSE - > PEF	0.29	10.07	0.24	5.26	0.29	7.44
JSEC - > PEF	0.27	8.71	0.25	6.17	0.35	9.11

Significant standards: t-value > 1.96.

or acting entrepreneurship tends to appreciate the power, independence, risk tanking, and innovativeness (Kirkley, 2016; Jones and Barnir, 2019). Likewise, results also support the direct and indirect association of intrinsic reward and Self-efficacy, whereas job security portrays significant negative impacts on PEF in the samples of China and Pakistan. The evidence backs up these results on self-efficacy and its positive relationship with entrepreneurial intentions (Schlaegel and Koenig, 2014), in which self-efficacy is identified as a driving force behind sustainability intentions. Because of the influence of job security in sustainable venture adoption, the findings show that it has a negative relationship with PED and that job security negatively impacts the antecedent of sustainable venture adoption. Such results are also consistent with previous research on entrepreneurial intentions, demonstrating that people concerned about their job security are less likely to start a sustainable business than those who place a higher priority on creativity and autonomy (Fitzsimmons and Douglas, 2011; Patzelt and Shepherd, 2016; Douglas et al., 2020; Sher et al., 2020).

Similarly, the findings support a direct correlation between environmental gain, intrinsic reward, and ATSE, showing that extrinsic reward has little effect on the latter. According to this research, the perception of an individual on environmental value creation significantly impacts their willingness to promote sustainable projects. These results are backed up by a study by Lyons et al. (2010) and Shepherd (2015) regarding the individual environmental value function and the implementation of sustainable business models. Furthermore, the results show a non-significant relationship between extrinsic compensation and attitudes toward SE adoption; in terms of the positive critical relationship between intrinsic reward and a theory of sustainable entrepreneurship, the study is in line with the current literature (Muñoz and Cohen, 2018; Domurath et al., 2020; Sher et al., 2020). This suggests a sustainable relationship between creativity and innovation and environmental and social value development that intrinsic reward positively affects attitudes toward sustainability (Sher et al., 2020; Shukla, 2021). The relevant findings of China vs. Pakistan samples are shown in **Figure 2** and **Table 7**.

Mediational Coefficient Analysis

Partial least squares structural equation modeling was used to assess the mediation results of proposed interactions. The protocol for mediation research proposed by Henseler et al. (2016) and Carrión et al. (2017) was used to test the hypotheses that ATSE, PEF, and PED play a mediating role in work values, job security, self-efficacy, and SEI. Furthermore, a bootstrapping technique was used as an inferential metric to measure the *t*-values for calculating the importance of proposed mediating factors. For the usable study sample, 5,000 sub-samples were produced (with replacement) during the bootstrapping process. As a result, the importance of mediating variables was calculated using bootstrapping inferential statistics on these subsamples. In path analysis, mediational refers to the indirect influence of the dependent variable that flows through one or more mediator variables (Edwards and Lambert, 2007).

According to the findings, PED thoroughly mediates the suggested paths between intrinsic rewards, extrinsic rewards, work stability, and SEI in Pakistan. In comparison, PED mediates the path between intrinsic rewards, job security, and SEI in China. The results indicate that extrinsic and intrinsic rewards are directly positive, while job security directly has significant impacts on SEI among both the country samples. These results confirm that intrinsic reward has the maximum indirect positive impact on the SEI and PEF in China. At the same time, job security shows the highest indirect positive effects on SEI and ATSE in Pakistan, which positively complements one work value creation into SEI. Hence, ATSE completely mediates the relationship between environmental value, intrinsic reward, and SEI. However, it also moderates the specific indirect positive connection between ENV and SEI; therefore, the proposed hypotheses (H1, H2, and H3) are accepted in the full and split data sets depicted in the **Table 8** and **Figure 3**.

TABLE 8 | Proposed hypotheses mediational effects among constructs of China vs. Pakistan.

Paths	Total Sample		China		Pakistan	
	β-coefficient	*t*-values	β-coefficient	*t*-values	β-coefficient	*t*-values
ENV - > ATSE - > SEI	0.13	7.27	0.11	5.43	0.13	4.89
EXTR - > ATSE - > SEI	0.03	2.92	0.02	1.67	0.05	3.50
INTR - > ATSE - > SEI	0.14	7.59	0.14	5.86	0.14	5.52
EXTR - > PED - > SEI	0.00	0.37	–0.01	1.81	0.03	3.29
INTR - > PED - > SEI	0.04	3.69	0.04	2.73	0.04	2.86
JSEC - > PED - > SEI	0.07	5.14	0.05	3.52	0.10	4.82
GSE - > PEF - > SEI	0.13	7.45	0.12	4.76	0.11	5.16
INTR - > PEF - > SEI	0.17	9.65	0.22	8.03	0.12	5.29
JSEC - > PEF - > SEI	0.14	8.53	0.13	5.58	0.13	6.45

Significant standards: t-value > 1.96.

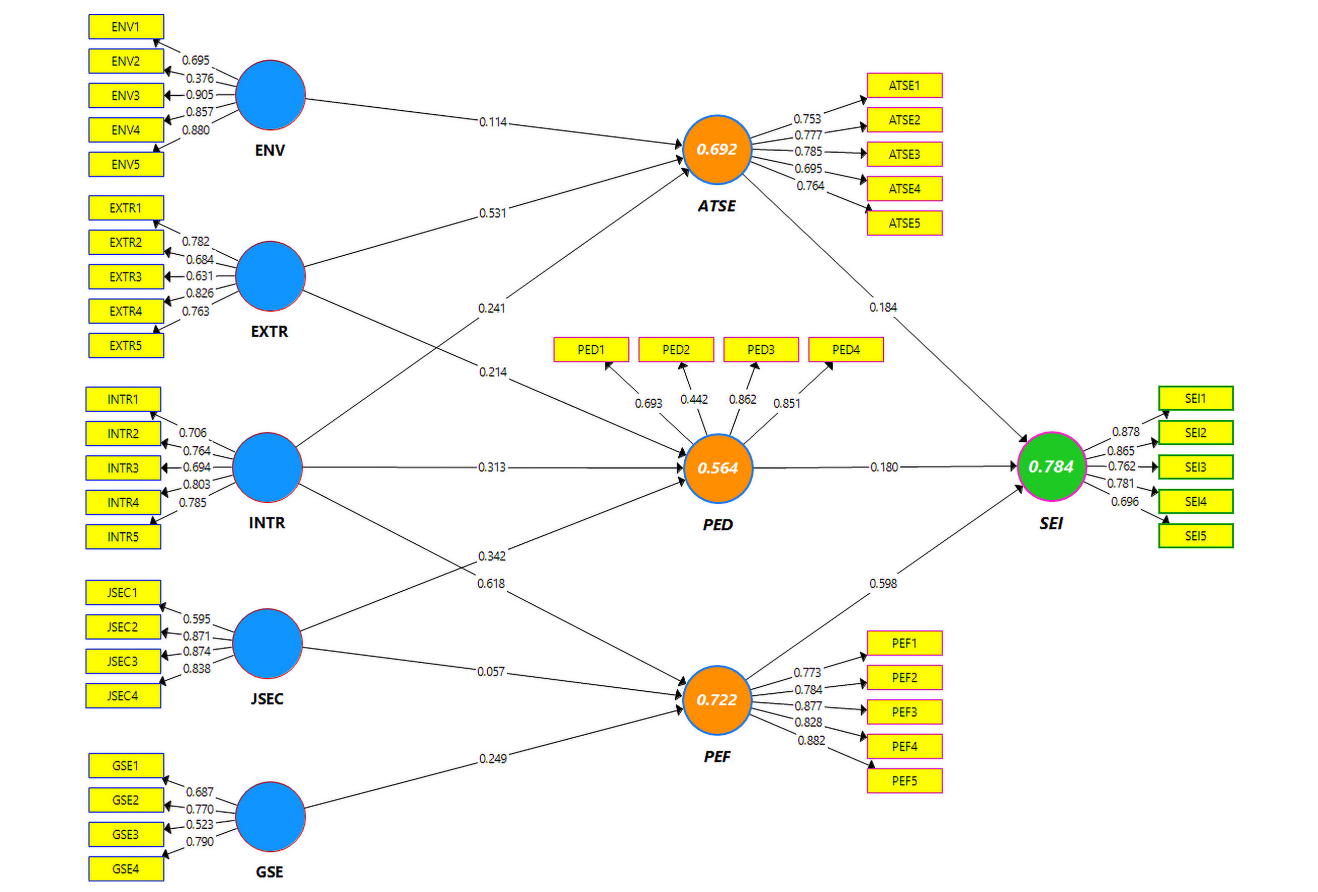

FIGURE 3 | Path coefficients and factor loadings of total sample model.

Consequently, H4, H5, and H6 are accepted, showing a significant relation with the mediational variables. The study finding entitles that ATSE translates environment value and intrinsic reward toward SEI. Thus, the higher is the motivation and preference for environment value and intrinsic reward, the higher is the SEI and vice versa with extrinsic rewards. Further, from the results, environment value has the second-highest indirect positive impact on SEI.

Similarly, the results show that PEF mediates the path relations among intrinsic reward, job security, and general self-efficacy for testing the H7, H8, H9, and SEI and designates that GSE and INTR show an indirect and positive influence on SEI. Therefore, the findings reveal that intrinsic reward and job security meet the mediational criterion developed by Baron and Ensley (2006), which illustrates that the antecedent of the predicted variable must be significantly related to the mediator.

H9 is also accepted as these constructs, i.e., intrinsic rewards, job security, and general self-efficacy satisfy the mediational criterion in the samples of both countries. These worth noting findings from the models of both the countries are to be discussed furthermore and are shown in **Table 9** and **Figure 4**.

Measurement Invariance

The Measurement Invariance process is required prior to conducting multi-group analysis before comparing the findings of Chinese and Pakistani samples. The main purpose of this test is to ensure that both groups interpret the measures in the same way. The measurement invariance of composite model (MICOM) methods are based on the latent variable scores, which represent these latent variables as composites, which are linear combinations of indicators, and the variable weights are calculated using the PLS-SEM technique (Henseler et al., 2016). This research used the MICOM (Henseler et al., 2016). The process of MICOM has the following three stages: (a) configure invariance assessment (the measurement models of both the groups have the same fundamental component structure); (b)

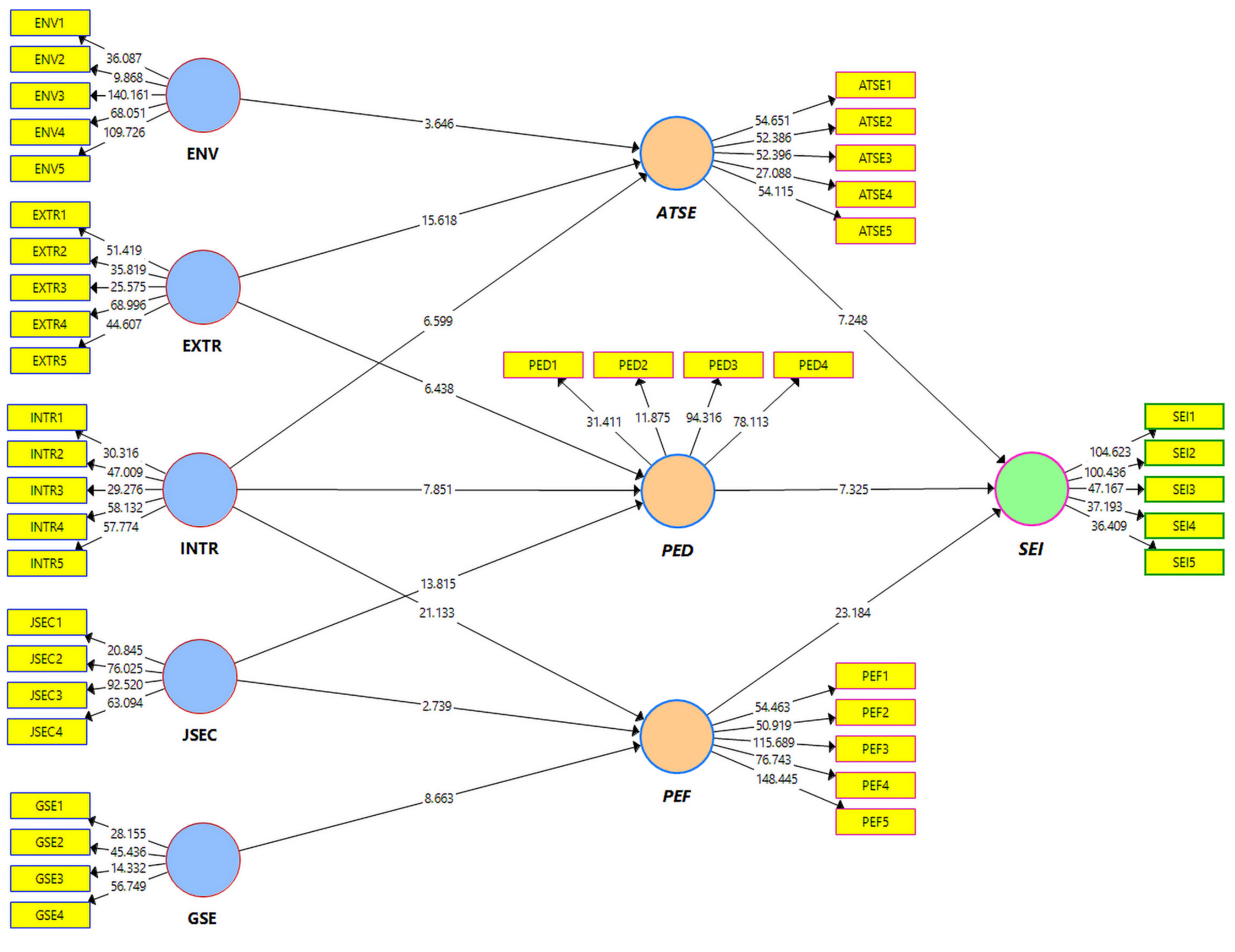

FIGURE 4 | Direct and indirect significant relationships of total sample model.

TABLE 9 | Total indirect effects among the constructs of China vs. Pakistan.

Paths	Total Sample		China		Pakistan	
	β-coefficient	*t*-values	β-coefficient	*t*-values	β-coefficient	*t*-values
ENV - > SEI	0.128	7.27	0.114	5.432	0.132	4.892
EXTR - > SEI	0.025	2.464	0.01	0.756	0.085	5.005
GSE - > SEI	0.125	7.447	0.122	4.755	0.108	5.16
INTR - > SEI	0.351	15.735	0.402	12.806	0.292	10.416
JSEC - > SEI	0.206	11.768	0.181	7.421	0.233	10.643

Significant standards: $t > 1.96$.

TABLE 10 | Compositional invariance of China vs. Pakistan.

Compositional invariance C = 1					Equal mean				Equal variance			
Constructs	**Configure invariance**	**C = 1**	**P- Mean**	**5% c**	**Partial MI established**	**Mean difference**	**2.50%**	**97.50%**	**Variances difference**	**2.50%**	**97.50%**	**Full MI established**
ATSE	Yes	0.998	1.000	0.999	No	0.421	–0.119	0.118	–0.25	–0.127	0.128	No
ENV	Yes	0.999	1.000	0.999	No	0.421	–0.12	0.121	–0.245	–0.128	0.122	No
EXTR	Yes	0.998	1.000	0.999	No	0.432	–0.123	0.123	–0.433	–0.127	0.119	No
GSE	Yes	0.997	0.999	0.997	No	0.497	–0.123	0.121	–0.243	–0.136	0.141	No
INTR	Yes	0.999	1.000	0.999	No	0.406	–0.119	0.124	–0.334	–0.124	0.125	No
JSEC	Yes	0.996	0.999	0.998	***Yes***	***0.113***	–0.117	0.119	–0.221	–0.141	0.143	Yes
PED	Yes	0.999	1.000	0.999	No	0.178	–0.123	0.12	–0.401	–0.122	0.121	No
PEF	Yes	1.000	1.000	1.000	No	0.403	–0.121	0.123	–0.127	–0.115	0.109	No
SEI	Yes	1.000	1.000	1.000	No	0.352	–0.117	0.124	–0.369	–0.125	0.125	No

Italic and boldface values violate the measurement invariance assumptions between China and Pakistan.

TABLE 11 | PLS-multigroup analysis of China vs. Pakistan.

Paths relationship	Path coefficients-diff (China—Pakistan)	*p*-value (China vs. Pakistan)
ATSE - > SEI	0.015	0.624
ENV - > ATSE	0.031	0.311
EXTR - > ATSE	0.011	0.571
EXTR - > PED	0.105	0.066
GSE - > PEF	0.006	0.552
INTR - > ATSE	0.046	0.748
INTR - > PED	***0.174***	***0.995***
INTR - > PEF	0.035	0.259
JSEC - > PED	***0.146***	***0.002***
JSEC - > PEF	0.030	0.749
PED - > SEI	0.022	0.325
PEF - > SEI	0.018	0.640

Italic and boldface values depict significant differences between China and Pakistan.

compositional invariance assessment (composite scores are not substantially different between groups); and (c) equality of composite means, values, and variances. If customizable and compositional variances are established, partial measurement invariance is verified, and the path coefficient may be compared between the two groups. Full measurement invariance is proven if partial measurement invariance is demonstrated and the composite has identical mean values and variance across all groups. The PLS-algorithm and PLS-permutation procedures, with a 5,000 sub-sample and a two-tailed test, were performed. The procedure compared the original score correlations (c) with the correlations obtained from the empirical distribution after running the permutation process (cu); compositional invariance is defined if c approaches the 5 percent quantile of cu (Henseler et al., 2016).

Multigroup Analysis

Finally, this paper also presented the PLS-Multigroup analysis (MGA) results, representing the differences between the path comparisons of China vs. Pakistan. The MGA method was used to compare the statistical differences between the two countries. For this purpose, we have devised (Henseler et al., 2009) a nonparametric PLS-MGA model approach to inspect the H10 results if the comparative relationship among work values, TPB magnitudes, and SEIs are likely to differ across the two countries in this study. However, the MGA results only differentiated the paths of the two countries with regard to JSEC-PED and INTR-PED (significantly). However, the results of MGA did not demonstrate the significant differences between both countries. According to the MICOM method, there is no need to proceed to the next stage if the compositional variance is not discovered; nevertheless, to give readers a better understanding, this research did perform the MGA, despite the fact that MGA is not relevant without verifying compositional invariance.

Thus **Tables 10**, **11** indicate that no partial measurement invariance for the two connections that were determined to be significant at *p*-value as the difference of group-specific route coefficients is either < 0.05 or > 0.95 (Henseler et al., 2009) indicating that compositional invariance was not discovered in the paths of the two countries, comparatively. Other routes were similar in both the countries, while the italic *p*-values indicate that significant differences between the two economies partially support H10.

DISCUSSION

This study has many functional and theoretical ramifications that are worth noting. These findings point to the factors that drive a plethora of sustainable start-up opportunities and entrepreneurship growth among aspirant entrepreneurs in China and Pakistan. First, the hypotheses (H1, H2, and H3) proposed that ATSE has a mediational relationship among work values, namely, environmental value, intrinsic reward, extrinsic reward, and SEI. The findings revealed that ATSE thoroughly mediates the significant positive relationship between ENV and INTR, but has a significant negative impact of EXTR on SEI in the samples of both countries can be seen in **Table 8**. PLS-SEM bootstrapping revealed that these hypothesized direct and indirect effects for full and split data set are highly significant. The intentions of the individuals to pledge sustainable ventures in China and Pakistan are positively correlated with work value creation, environmental values, and intrinsic rewards predicted certain behaviors and desires for sustainable businesses in both countries. Regarding the outcomes on the intrinsic and extrinsic rewards, the results of the current study are supported by the work of Short and Hawley (2015), Kirkley (2016), Sargani et al. (2020), and Sher et al. (2020), encouraging the effect of intrinsic and extrinsic rewards in the uptake of sustainable ventures in the United States, New Zealand, Pakistan, and China, which was accompanied by the substantial and encouraging effect of intrinsic and extrinsic rewards in the uptake of sustainable ventures.

These findings indicated that the more the aspirant entrepreneurs value hegemony, independence, risk-taking, and ingenuity, the more likely they become future sustainable magnates. In terms of the inverse function of work security, the pragmatic analysis (Patzelt and Shepherd, 2016) based on graduate alumni of Australian universities from the United States, Europe, India, and China with relative comprehension indices, show that the individuals have lower long-term market ambitions and higher job stability. As a result, in contrast to intrinsic and extrinsic rewards, individuals who prioritize career stability and job longevity have lower long-term market uptake intentions than people who value creativity and freedom (Twenge et al., 2012; Sher et al., 2020).

In addition to the H4, H5, and H6, the PED in China and Pakistan indicates a mediational interaction among intrinsic reward, extrinsic reward, and job security, on SEI. The findings support theories for environmental value and intrinsic reward in terms of the mediational function of PED. In the samples of both countries, the bootstrapping study revealed that PED significantly mediates the relationship between extrinsic reward, intrinsic reward, and job security on SEI (Fitzsimmons and Douglas, 2011; Sher et al., 2020). Similarly, extrinsic rewards show a meaningful relationship with PED in full and split datasets of the model. Also, in the study of Baron and Ensley (2006), the PED reached the mediational targets. However, in our study, the intrinsic reward revealed a higher direct and indirect impact on SEI of both samples shown in **Table 9**.

These results are consistent with those of Liñán and Fayolle (2015) and Sher et al. (2020), who investigated the effects of workable values, inspiration, and intentions on SEI Spain, based on an analysis (Majid and Koe, 2012; Koe et al., 2015; Sher et al., 2020) in Malaysia and Pakistan, respectively, showing that intrinsic incentive and ATSE are the predominant motivators for pursuing the sustainable enterprise. Similarly, (Fitzsimmons and Douglas, 2011; Sargani et al., 2020) in India, China, Australia, and Thailand, a comparative analysis of aspiring entrepreneurs was conducted and pointed out that attitudes of the people toward sustainability and their job beliefs are essential considerations in determining potential venture adoptions. The work of Sargani et al. (2020) and Sher et al. (2020) found that positive actions, a sustainable mindset, and entrepreneurial viability are guiding factors in sustainable intentions and uptake of sustainable performing projects, which corroborate the results of this report. In a related way, these results are consistent with the findings of Shepherd and Patzelt (2014), Domurath and Patzelt (2019), Sargani et al. (2020), and Sher et al. (2020), with regard to the connections between environmental value and long-term sustainable goals. These findings suggest that a higher degree of ecological benefit and intrinsic compensation is linked to a more optimistic outlook toward implementing sustainable enterprises.

The current study on the hypotheses of China vs. Pakistan (H7; H8; H9) confirmed that PEF mediates between intrinsic rewards, job security, and self-efficacy, on SEI, in both countries. The findings endorsed all independent connections on SEI interactions, such as intrinsic reward, job stability, and self-efficacy. Whereas in China, the intrinsic reward had a higher indirect impact, and job security had a more substantial indirect influence on PEF, resulting in it being a center of mediation due to its capacity to meet the preconditions of mediational research (Baron and Ensley, 2006; Carrión et al., 2017). The bootstrapping study shows that the PEF has significant mediating effects between intrinsic rewards, work safety, self-efficacy, and SEI in the samples of both countries. Prior literature on sustainability goals provides sufficient evidence for the importance of job security and general self-efficacy in this research (Chen et al., 2001; Shepherd and Patzelt, 2014; Diallo, 2019; Sargani et al., 2020). As a result, the results of the study support the idea that the greater is the self-efficacy of a potential entrepreneur, the more likely they are to have sustainable start-up business plans.

Finally, this paper presented the PLS-MGA model approach to check the results of H10 if the comparative relationship between work values, TPB magnitudes, and SEIs are likely to differ across countries. Thus **Tables 10**, **11** show that there was no measurement invariance determined to be significant at *p*-value, for the difference of group-specific route coefficient are either < 0.05 or > 0.95 (Henseler et al., 2009) indicating that compositional invariance was not found in the paths of the two countries, comparatively, whereas the italic *p*-values indicate that significant differences between the two economies partially support H10.

Sustainability-Oriented Model From a Theoretical Perspective

The research provides a deeper explanation of the applicability of TPB in SEI from a theoretical standpoint. A development to estimate SEI is suggested, and it can also be applied to another stereotype-specific entrepreneurship (Schaefer et al., 2015). The study adds to the existing literature on entrepreneurship by revealing how different entrepreneurship aim models can be tailored to suit the specific context (Shepherd and Patzelt, 2014). This study added to the SEI literature by creating a symbolic structure for long-term job value and testing it in two countries (China and Pakistan). The findings suggest that using a combined model is a viable option that has gained little coverage in the literature.

The findings of this analysis strongly reinforce the notion that the TPB should be used while researching type-specific entrepreneurial intentions (Ajzen, 1991; Liñán and Chen, 2009). The findings of the report back up the findings by Liñán and Fayolle (2015), Sargani et al. (2020), and Sher et al. (2020) that recommend using aim models and demonstrate how they can be extended to different types of entrepreneurship intentions. To put it another way, it means that they adopt substantially. In a nutshell, understanding the differences in entrepreneurial opportunities is essential for implementing different entrepreneurial models. Besides, the thesis explores SEI drivers by incorporating various aim models into SE models. It broadens the range of viable alternatives and the range of options available to young people.

Implications for Practice and Policy Based on New Insights

The paper contributes to the emerging literature on SE by including fresh policy ideas and current experiences. First, it discusses how various job principles influence the attitude of an individual toward long-term entrepreneurship in various economies. Furthermore, the prior literature by Patzelt and Shepherd (2016), Lundmark et al. (2019), and Sher et al. (2020) advocated for the internal balancing between principles, assumed skills, and motivations in constructing SE. At the same time, it resulted that the career of an individual and professional decisions, which are closely linked to workable values and that the decision to proceed on a sustainable endeavor is likely to be influenced by their expectations for the work environment (Jaén and Liñán, 2013; Hsu et al., 2017; Sher et al., 2020). The findings show that workable principles are important motivators and building blocks for a positive attitude toward sustainability and SE (Parra, 2013).

Second, the findings add to the growing body of knowledge in the field of SE about the relationship between job principles, behaviors, and intentions (Avey et al., 2010; Sher et al., 2020; Shukla, 2021). Furthermore, the findings of the study also provide helpful information on enterprise viability and desirability by advancing a substantial mediating impact on the SEI of students.

Third, the findings are similar to those of Hewlett et al. (2009) and Sher et al. (2020), which also asserted that millennials are environmentally aware and have a higher attitudinal tendency toward sustainable enterprises. They further emphasize the importance of providing young entrepreneurs with benefits rather than cash rewards for their start-workups.

Finally, as a result, the environmental enterprise will become a central motivating force for our shared future sustainability. In both economies, our mutual future market prosperity is a vital driving force in leapfrogging the degree of SEI influence. The SE progressive management approach will create new business systems, markets, and services in creating new goods and services. In the enterprise process, the SE innovative management approach will generate new goods and services and increase the impact of social and environmental business operations in the future.

CONCLUSION AND POLICY IMPLICATIONS

All in all, this research has made a significant contribution to the literature on SEIs by creating an expanded framework of TPB that incorporates the function of individual work values, and by testing this model in two different nations (China and Pakistan). The findings indicated that there was support for this integrated model approach, which had received little attention or emphasis in the literature up to this point. Students from both countries are expected to launch their own sustainable businesses. However, the comparatively stronger intentions are shown by Pakistani students. In the context of the sustainability values disposition, this study has contributed toward theoretical underpinning for suggesting a new understanding of outlook by including work values (i.e., ENV, JSEC, GSE, INTR, and EXTR (rewards) along with the meditational role of three attitudinal magnitudes of TPBs though comparing two economies (i.e., developing and emerging). The results found the stronger role of work values of sustainable business inclinations and its effect on attitudinal dimensional among students from a developing country; these variables explain the impacts of specific country context. The results advocate that students from both countries show positive sustainable oriented intentions toward self-employment and sustainable enterprises. However, this study only compares one efficiency-driven economy (China) and one factor-driven developing country (Pakistan); inevitably the results are generalizable only to these countries only.

Research and Practice Implications

This paper enriches the existing literature in three research streams. First, it enriches the literature on SEI and TPB models. Several prior studies have predicted SEI cross-culturally by exploring the role of cultural, demographic, socio-economic, and several other variables; this study contributes to the existing research by showing how work values and TPB together affect SEI). The findings related to work values make an explicit comparison to explain differences in SEIs between the two countries.

The findings of this study provide new insights into the existing literature on SE. First, by contributing to the sustainability work values that are important for developing theories related to the entrepreneurial process and behavior, how different work values drive the attitude of an individual toward the uptake of SE.

Second, this paper attempts to strengthen the role of TPB and its magnitudes. These findings highlighted the validity of the TPB model, elaborate on the mediating role of its attitudinal dimensions of TPB, and also provide a comparative understanding of TPB and its extents in each country. In addition, the findings of the study offer valuable insights on perceived venture feasibility and desirability by advancing a significant mediating effect on the SEI of the students.

Third, this study enriches the literature on an integrated model of personality and TPB by providing comparative roles of this integrated model regarding two economies (i.e., emerging and developing). The results provide an in-depth understanding of these variables and extend the existing literature with respect to sustainability work values and TPB. In addition, the findings of the study offer valuable insights on perceived venture feasibility and desirability by advancing a significant mediating effect on the SEI of the students in the two Asian countries.

Policy Implications

This study also suggests implications for universities, institutions, and policymakers to design policies that can enhance sustainable entrepreneurial culture in both countries. Based on the research findings, the authors recommend that new regulations must be implemented to help students develop sustainable business practices. Less risk taking, more effective implementation of sustainable entrepreneurial concepts, and finding possibilities should be the educational approaches of the universities. Universities in both countries should offer new educational techniques including expert instructors and successful entrepreneurs to foster values of innovation, creativity, and risk-taking, particularly among Pakistani students. Decision makers should plan and develop policies at the government and institutional levels to foster a sustainable entrepreneurial culture by ensuring the protection of aspiring entrepreneurs. There is a need to compensate prospective entrepreneurs for their efforts in ways other than monetary compensation, which may allow the SEI to rise to a higher level in both countries.

In this manner, sustainable possibilities will increase the likelihood of sustainable start-ups and encourage SE in both economies. As a result, the research has implications for promoting sustainability-driven work values and endorses that work values should be given greater emphasis in accelerating individual attitudes toward SE. Using the practices of role models in the industry and engaging with them to create a good picture of sustainable enterprises would be one potential approach to increase the adoption of SE as a profession while also driving sustainable development.

Future Prospects

On the other hand, sustainable agribusiness is a collection of activities and a community-wide bargaining mechanism that pushes and pulls overlapping forces to address the emotional issue of preserving food and fiber. Similarly, inspiring nonbusiness people to pursue entrepreneurship may be another way to significantly affect the extent of long-term entrepreneurial aspirations and subsequent implementation. Creating opportunities for capacity development at educational institutions, as well as fostering themes of competitive venturing within established enterprises, will prove to be tremendous feedback in encouraging such entrepreneurs across diverse countries to satisfy the need of the current society for food and fiber without jeopardizing the potential of the future generations to cope using its resources. In the end, it would take a typical mentality and wisdom to assist our society in overcoming the most difficult challenges using creative business approaches. The active participation of youth in sustainable development activities is critical to creating sustainable, equitable, and healthy economies by the target date, as well as averting the worst risks and challenges to sustainable development, such as the effects of climate change, gender disparities, war, displacement, probability, unemployment, and poverty alleviation, especially in rural settings.

Limitations

The research still has several drawbacks, one of which opens up new possibilities for future researches. To begin with, the suggested relations in this study are context-specific, respectively, sustainable value formation and sustainable entrepreneurship, and did not consider the distinction between actual actions (reality) and purpose (perception) (Liñán and Chen, 2009). Second, a possible restriction is the sample size, which was limited to eight agrarian university students from only two Asian nations. A study providing a solid foundation for the inquiry will strengthen support for the proposed model and provide a comparative image of distinct classes of individuals, giving proper assistance to suggested ties that may be homogeneous economies. Third, gender was not included in this study; however, considering the role of gender, especially in emerging and developed economies, would strengthen the existing model. As a result, a larger-scale analysis is needed to generalize the results. Despite its shortcomings, this study offers valuable guidance to academics, policy planners, and government entities, allowing them to make informed decisions on improving and expanding SE in both economies. It should look at these links through various entrepreneurship opportunities representing different tiers and types of businesses for future generations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee College of Economics, Sichuan Agricultural University, Chengdu. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

GRS: data curation and software. GRS and AAC: formal analysis and validation. GRS, AAC, and MH: investigation, writing—review, and editing. GRS, DZ, and YJ: resources, visualization, and supervision. GRS, NK, and MH: data entry. All authors have read and approved the final version of the manuscript.

FUNDING

The current research was sponsored by the National Social Science Fund of China Projects Fundamental Research Funds for the Central Universities Research and the Priority Academic Program Sichuan Agricultural University (Grant No. 20AJ011).

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ORIGINAL RESEARCH
published: 23 December 2021
doi: 10.3389/fpsyg.2021.747961

Effectiveness of Metacognitive Regulation Intervention on Attention-Deficit–Hyperactivity Disorder Students' Scientific Ability and Motivation

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OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: 27 July 2021
Accepted: 25 November 2021
Published: 23 December 2021

Citation:
Zheng HY, Dong Y, Sun YK, Yang J, Yuan CB, Wang JD and Dong WY (2021) Effectiveness of Metacognitive Regulation Intervention on Attention-Deficit–Hyperactivity Disorder Students' Scientific Ability and Motivation. Front. Psychol. 12:747961. doi: 10.3389/fpsyg.2021.747961

This study investigated the effect of metacognitive regulation (McR) intervention on attention-deficit–hyperactivity disorder (ADHD) students' astronomy knowledge acquisition and learning motivation. Through a cognitive-behavioural treatment design, this study selected 97 ADHD learners who had poor academic performance. This study divided ADHD students randomly into one experimental group and one control group. After 15 weeks of intervention, results showed that the experimental group students performed significantly better than the control group in scientific abilities, learning motivation, and metacognition. Results suggested that the McR intervention is an effective approach for improving the ADHD students' science knowledge learning abilities.

Keywords: metacognition, ADHD learners, regulation effect, dynamic interaction model, astronomy, primary school

INTRODUCTION

Metacognitive regulation (McR) refers to an ability to modify cognitive processes and strategies to remain in control of their learning conflicts; it describes how students monitor and control their knowledge acquisition process (Zimmerman, 1995; Fernandez-Duque et al., 2000; Efklides, 2008). These McR abilities are implemented in McR activities and further comprised more concrete regulation strategies, such as presented task analysis, learning content orientation, task perception awareness, task problem-solving decomposition, progress monitoring, collaboration monitoring, evaluating learning outcomes, and evaluating the learning process. McR activities depend on the regulative agents involved and their underlying intentions, which include students' individual learning, collaborative learning with classmates or peers, or based on a group collaborative learning process (Lajoie and Lu, 2012; Rogat and Adams-Wiggins, 2014; De Backer et al., 2015). Insufficient development of McR may generate the students' knowledge misconception in a science discipline (Greene and Azevedo, 2010; Khosa and Volet, 2014; Ucan and Webb, 2015) and learning difficulties

(Hurme et al., 2009; Jokić and Whitebread, 2011; Dragan, 2015; Goudas et al., 2017) and decrease the students' learning motivation (Paris and Winograd, 1990; Sungur, 2007; Zimmerman and Moylan, 2009).

Previous studies have shown that the students' awareness of McR can also be raised through observation of the modelled McR during peer interactions within students (e.g., collaborated learning) (De Backer et al., 2015; Raes et al., 2016), individual personal self-checking by providing McR rubrics (Papaioannou et al., 2012), and team-based learning supervised by an instructor (De Backer et al., 2016). The current literature has demonstrated the value of team-based learning when supervised by an instructor at the McR intervention (Schraw et al., 2006; De Backer et al., 2016; Hadwin et al., 2017). During this format intervention, previous studies report that students explicitly felt the need to regulate the learning interactions amongst instructors, peers, presented knowledge, and the learning processes taking place because they are reminded or required to engage in the collaborative goal set by the instructor and attend conceptual discussions with peers or groupmates, to control their own comprehension and check on learning outcomes collaboratively (De Backer et al., 2016; Hadwin et al., 2017).

Metacognitive regulation is easier to be trained and developed in an early school age than later in the school career (Kuhn, 2000). The previous cognitive apprenticeship paradigm suggests that the students' McR awareness can emphasise learning through guided practice (Collins et al., 1988). Previous studies demonstrate that the key approach to develop the students' McR awareness is to promote prompting the evaluation of their performance, compared with expected learning outcomes (Hadwin et al., 2005). Students can be challenged to internalise the expected behaviour at the individual level, which requires regulative practice in settings (De Backer et al., 2016). Moreover, an interactive learner–teacher learning format can be established, which prompts students to clarify, control, judge, and regulate their learning, which is aimed at consolidating metacognitive knowledge and skills (Schunk and Zimmerman, 2007).

Previous studies have shown that McR treatments improved the students' performance in mathematics (Desoete et al., 2003; Bol et al., 2016; Vula et al., 2017), science (Abd-El-Khalick and Akerson, 2009; Peters and Kitsantas, 2010; Zepeda et al., 2015), and engineering (Clancey, 1988; Vrugt and Oort, 2008). Astronomy knowledge, which provides great learning resources on the students' scientific ability development (e.g., spatial thinking and mathematical thinking skills' application), has been less concerned. Astronomy knowledge in primary school introduces relevant concepts and knowledge in terms of celestial body units (e.g., Earth, Sun, and Moon). Astronomy knowledge has unique characteristics in typical knowledge integration (e.g., integrating mathematics and geography) and contributes to the learners' problem-solving abilities. Moreover, students can learn the principles of natural laws easily in learning astronomy. Astronomy knowledge not only provides typical natural knowledge to students, but also offers great potential scientific thinking opportunities. However, only a few studies have explored the McR intervention effect in astronomy knowledge learning.

Students who have ADHD symptoms usually experience more disruptive and off-task behaviours than typical developing peers (Tamm et al., 2014; Pezzica et al., 2018). Studies have demonstrated that ADHD students have experienced high levels of learning stress and may have an increased risk for mental health disorders (Evans et al., 2020). Behavioural interventions are promising as ways to improving attention span and impulsivity in the development of academic performance (e.g., ability, learning motivation). Extensive studies have applied intervention designs to address learning problems (e.g., attention difficulties) for ADHD students. For example, the cognitive-behavioural treatment design, including knowledge translation or clarification and phenomena reason elaboration, has been confirmed as an effective approach to promote the ADHD learners' academic performance (Hasson-Ohayon, 2012; Pöttgen et al., 2015; Moritz et al., 2019). Moreover, previous studies have shown that group learning will benefit more ADHD learners than individual independent learning (Tamm et al., 2014; Pezzica et al., 2018). Previous studies have also confirmed that the teacher-mediated instructional approach is more effective than the printed words instructional approach on the ADHD students' cognition treatment (Hacker et al., 2019). McR emphasise cognitive control during the learning progress. However, the McR approach benefits on the ADHD students' attention defect and academic performance remains unclear.

The dynamic interactional model (DIM; Toglia, 2018) in learning emphasises that learning is a continuous product of the dynamic interaction between the individual, task, and environment. Under the science education context, the use of McR can be promoted through a wide range of meaningful activities by improving activity management with strategy intervention (Josman and Regev, 2018; Toglia, 2018). However, whether the statement on DIM can be extended for ADHD students remains unknown, especially in the astronomy knowledge learning context.

The Current Study

To address the aforementioned problems, this study aims to investigate the effect of McR intervention on the primary school ADHD students' academic performance in the astronomy knowledge domain. Within the astronomy learning context, this study implements the McR intervention to primary school ADHD students, exploring the possible improvements in the ADHD students' metacognition, learning motivation, and scientific ability, thus applying the DIM statement in ADHD students' behaviour treatment in an astronomy learning context. The following research questions and correspondence hypotheses are listed as follows:

Research question 1: Does McR intervention significantly improve the ADHD students' scientific ability?
Research question 2: Does McR intervention enhance the ADHD students' science learning motivation?
Research question 3: What is the effect of McR intervention on the ADHD students' metacognition development?

MATERIALS AND METHODS

Participants

This study recruited 97 ADHD grade 5 primary school students from one typical primary school in Chengdu, China. All 97 students fulfilled the full DSM-IV criteria for ADHD at the age of 10, which were included into this study. The DSM-IV home version is a caregiver-reported rating scale that has been widely used in ADHD studies of primary school children (Roberts et al., 2019; Pang et al., 2021). The scale has strong discriminant validity both within the ADHD subtypes and between children with ADHD and without ADHD. The psychometric properties of the Chinese version of this scale also have been validated for the use amongst children aged 6–17 years in China (Su et al., 2015). The ADHD DSM-IV asks the child's primary caregiver (kids' teacher or guardian) to rate the frequency of 18 ADHD symptoms that occurred over the past 6 months. The primary caregiver is defined as the students at home or school most often responsible for the student's care, typically the mother or paternal. Symptoms were rated on a four-point Likert scale, for which 0 = rarely or never, 1 = sometimes, 2 = often, and 3 = very often. To easily interpret the results, we use average scores to report the result, and scores for each item were then summed to reach a total score that ranged from zero to 3 points. Previous studies have found that a cut-off point of 2 yields optimal sensitivity and specificity in distinguishing children at risk of ADHD amongst students in urban China (Su et al., 2015; Tong et al., 2018). Following these methods, we similarly consider children with average scores above 2 to be at risk of ADHD. All participants should be diagnosed with at least four symptoms of inattention or hyperactivity (with a rating of "2" or "3," mean = 2.62, SD = 0.17) on the DSM-IV rating scale (Nigg, 1999). To lower down the risk of ADHD diagnosis, clinical interviews were applied by trained medical centre health care professional officers at students' school. Participants received neuropediatric or psychiatry services at school medical centre every year. In addition, participants received new round neuropediatry or psychiatry services at school medical centre 1 month ago before the intervention. All participants were ADHD students without any other comorbid problems (e.g., listening difficulties). The reason why we selected Grade 5 students as participants is that all Grade 5 students have the basic required learning experience in science knowledge, ensuring that the learning content will not be overloaded. All students had poor academic performance in Chengdu's standard multidiscipline examinations. Moreover, all students had poor performance in science subjects and all these students came from low-income families. The 97 ADHD students were randomly assigned into one experimental group (EG) and one control group (CG). As a result, the EG had 49 ADHD students (25 boys, 24 girls, mean age = 9.74, *SD* = 0.45) and CG had 48 ADHD students (24 boys, 24 girls, mean age = 9.84, *SD* = 0.42). The difference analyses (one-way ANOVA and chi-square) showed that no significant differences exist amongst the ADHD students (EG and CG) in the standardised test of scientific abilities in astronomy [$F(1,96) = 1.17$, $p > 0.10$], non-verbal intelligence [$F(2,151) = 0.46$, $p > 0.10$], age [$F(2,151) = 1.37$, $p > 0.10$], and gender distribution [χ^2 $(2,151) = 1.09$, $p > 0.10$], ensuring that the minimum benchmark of EG and CG was satisfied. No students have quit from the study during the intervention period. All students attended more than 80% of the intervention sessions.

Research Procedure

The intervention design and measurements were reviewed by two Chinese science scholars and two primary school science teachers to ensure the teaching content validity before the implementation of the intervention programme. The curriculum teaching design was refined based on the feedbacks from both scholars and science subject teachers.

The selected measurement parameters (consistent reliability index and confirmatory factor analysis) of the final version, which was applied to the main study, are reported in **Table 1**. This study followed the major analysis and statistical tools from the confirmatory factor analysis: chi-square statistics, comparative fit index (*CFI*), the Tucker–Lewis index (*TLI*), root mean square error of approximation (*RMSEA*), and standardised root mean square residual (*SRMR*). Kline (2005) suggested that for *RMSEA* values below 0.08, *SRMR* equal to or less than 0.05 and *TLI* and *CFI* values greater than 0.90 are considered to be acceptable in model fitness.

To control the effect from the instructor (e.g., instructional style, teaching experience, and familiarity level of astronomy knowledge) on McR intervention implementation, this study randomly selected a science teacher as the instructor from the participants' school. Furthermore, this instructor received a workshop before the intervention programme. At the workshop, one research collaborator presented a checklist to this instructor to remind what the instructor expected to do in EG, including the time arrangement for each teaching section, principles of McR word use to EG students, and the detailed information (e.g., key concept of McR) for instructional word suggestions to EG and CG students.

All participants were required to take the metacognition test, science learning motivation survey, and science thinking test, each of which with a pretest, posttest, and a 2-week delayed posttest. The metacognition test, science learning motivation survey, and science thinking test lasted for 15, 15, and 10 min, respectively. At the pretest, students took 50 and 15 min on the non-verbal intelligence test and working memory test, respectively.

Experimental Design

A quasi-experiment with a pretest, posttest, and a 2-week delayed treatment-control group design was applied. EG and CG received a treatment-control group design in the same digital classroom to remove the effect of available resources (e.g., astronomy model utilisation). McR intervention was inserted into the students' astronomy learning activities for the EG group, whilst the CG students received the typical activities instruction (e.g., group discussion on what they learned) during the same time when EG students received the McR component. The difference between EG and CG

TABLE 1 | Reliability index and goodness-of-fit for the selected instruments.

Subscale	No. of items	Cronbach's alpha			Goodness-of-fit index					
		Pretest	Posttest	Delayed posttest	χ^2	*df*	*TLI*	*CFI*	*SRMR*	*RMSEA*
Non-verbal intelligence	60	0.82								
Metacognition test					2342.34	568	0.97	0.98	0.02	0.03
Knowledge	9	0.86	0.87	0.87						
Experience	6	0.85	0.86	0.86						
Regulation	10	0.80	0.82	0.82						
Learning motivation					732.85	297	0.90	0.92	0.05	0.08
Interest	5	0.77	0.78	0.78						
Competence	5	0.72	0.73	0.73						
Effort	5	0.65	0.69	0.69						
Evaluation	5	0.78	0.80	0.80						
Pressure	5	0.74	0.76	0.76						
Scientific ability					125.72	34	0.91	0.91	0.04	0.07
Mathematical	4	0.65	0.68	0.68						
Spatial	4	0.71	0.75	0.75						

is the inserted learning activity design: EG received McR practices and CG received typical group discussion practices. The learning pace, learning materials for astronomy knowledge, and the number of learning sessions were similar between EG and CG students.

Instructional Design

Metacognitive regulation practices for EG students included monitoring and evaluating two components. The instructor required EG students to conduct McR practices at the last 10 min of the session, whilst EG students were required to evaluate their performance of astronomy knowledge acquisition and observe whether they had already achieved the expected performance requested by the school syllabus. CG students were required to conduct group discussions on what they have learned in the current session and how to implement the astronomy knowledge into practical problem-solving. CG and EG students received no feedback on their performance at every last-minute activity. The formal intervention comprised 15 science sessions through two modules, with each module including seven to eight 45-min science lessons. The first eight contents focussed on the natural knowledge relevant to the Earth (i.e., Earth rotation), and the rest was related to astronomy knowledge teaching (i.e., the correlation amongst the Earth, Moon, and Sun). **Supplementary Appendix 1** provides the list of teaching and learning content in a science subject. **Supplementary Appendix 2** presents the example questions for each category of McR principles.

Measures

Non-verbal Intelligence Test

A full version of Raven's standard progressive matrices (sets A–E) was used. Each item was presented with a portion missing. Students were required to select one piece from the provided six to eight options to complete the matrix items. There were 60 items and the maximum score was 60.

Metacognition Ability Test

This test was modified from the math metacognition ability test in the Chinese version (Lan, 2014) to fit the context of astronomy science in this study. The test comprised three 5-Likert subscales to assess the students' metacognition knowledge, metacognition experience, and McR. The knowledge scale had nine items, assessing the students' awareness on the link amongst science learning outcome or production, exploration activity design, and the principles (example items: I think I can handle the science principle application on a science knowledge test and I can do well). The maximum mean score on the knowledge scale was 5. The experience scale had six items, assessing the students' cognitive feelings and corresponding affective feeling (example item: I have a clear awareness on the difficult level evaluation of the given science subject task). The maximum mean score of the metacognition experience test was 5. The regulation score had 10 items, assessing the students' awareness of science knowledge activity progress monitoring ability (example item: I have a clear mental guideline on how to solve the given science problems *via* separating into more specific steps). The maximum mean score of the McR test was 5.

Science Learning Motivation

This questionnaire was modified from the Chinese primary school students' math learning questionnaire (Rao et al., 2000), which was validated in the previous studies in Chinese participants (Ndijuye and Rao, 2019). This questionnaire aimed to measure the students' science learning motivation through five six-item, five-point Likert subscales: interest, competence, effort, usefulness, and pressure. The maximum mean score for each subscale was 5. Specifically, the interest scale assessed the students' self-awareness on science subject learning interest and enjoyment (example item: I think learning science knowledge is interesting). A higher score represented a higher science learning interest. The competence scale assessed the students' self-evaluation on science knowledge learning ability (example items: I am satisfied with my learning performance in science knowledge acquisition). A higher score represented a higher science learning competence. The effort scale assessed the students' self-evaluation on self-intrinsic learning effort (example item: I exerted a huge amount of effort on learning science). A higher score represented a higher science learning effort. The usefulness scale assessed the students' self-evaluation on the importance of scientific knowledge acquisition (example item: science knowledge is convenient to my lifestyle). A higher score represented the high usefulness of self-assessment on science learning. The pressure scale assessed the students' negative emotion (anxiety and pressure) on science knowledge acquisition (example item: I have learning anxiety on the science subject). The pressure scale had an inverted score account; thus, a higher score can reflect a lower science learning pressure.

Scientific Ability

This test consisted of two four-item subtests: the mathematical ability test and the spatial thinking ability test. The mathematical ability test assessed the students' habits in the mind of both algorithm principle applications on mathematical problem-solving. Any correct answer was awarded one score. The maximum score of the mathematical ability test was 4. Items in the spatial ability test can measure the students' spatial thinking logic and abstract thinking of the object's location. Any correct answer was awarded one score. The maximum score of the spatial ability test was 4.

TABLE 2 | Descriptive analysis.

		Pretest		**Posttest**		**Delayed Posttest**	
Variables	**Group**	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
Non-verbal Intelligence	EG	25.52	1.96				
	CG	25.48	1.95				
Knowledge	EG	2.21	0.09	3.82	0.19	3.84	0.19
	CG	2.21	0.09	2.24	0.17	2.27	0.22
Experience	EG	1.42	0.28	3.18	0.28	3.21	0.29
	CG	1.42	0.29	1.46	0.32	1.49	0.36
Regulation	EG	2.88	0.16	3.18	0.17	3.17	0.17
	CG	2.88	0.16	2.90	0.17	2.93	0.18
Interest	EG	2.64	0.90	3.06	0.85	3.08	0.87
	CG	2.63	0.91	2.62	0.89	2.58	0.90
Competence	EG	2.38	0.78	2.74	0.78	2.75	0.79
	CG	2.38	0.79	2.38	0.79	2.37	0.79
Effort	EG	2.57	0.84	2.98	0.84	2.98	0.84
	CG	2.55	0.85	2.55	0.85	2.55	0.85
Evaluation	EG	2.64	0.87	3.28	0.88	3.28	0.88
	CG	2.63	0.87	2.61	0.88	2.60	0.88
Pressure	EG	2.41	0.74	2.03	0.74	2.03	0.74
	CG	2.42	0.73	2.42	0.73	2.42	0.72
Mathematical	EG	1.23	1.04	3.10	0.93	3.21	0.89
	CG	1.12	0.80	1.78	0.82	1.80	0.99
Spatial	EG	1.37	1.06	3.25	0.90	3.04	1.01
	CG	1.32	1.02	1.72	1.01	1.92	1.14

EG, experimental group; CG, control group.

RESULTS

To address aforementioned research questions, the section "Results" contained two components. First, it provided the descriptive analysis to provide the demographical information of participants and test the normality assumption. Second, it provided the available reason to apply repeated measures to conduct the inferential analysis.

Descriptive Analysis

The mean score and standard deviation of non-verbal intelligence, metacognition, science learning motivation, and scientific ability across the pretest, posttest, and delayed posttest are all presented in **Table 2**. Moreover, the skewness and kurtosis test have shown that all indicators were within ± 2, indicating that no significant outliers are included in this study (Small, 1980; Hopkins and Weeks, 1990).

The Effects of Metacognitive Regulation Intervention on Students' Metacognition Ability, Science Learning Motivation, and Scientific Ability

A repeated measure analysis of variance was performed to compare the students' metacognition ability (knowledge, experience, and regulation), science learning motivation (interest, competence, effort, evaluation, and pressure), and scientific ability (mathematical and spatial ability) across the pretest, posttest, and delayed posttest on the students' perceived instruction across different treatment groups. The heterogeneity test shows that all selected variables had insignificant heterogeneity ($p > 0.05$). Furthermore, Mauchly's test of sphericity showed that the Mauchly's W were insignificant ($p > 0.10$) amongst metacognition ability, science learning motivation, and scientific ability, indicating that the heterogeneity effect was insignificant amongst metacognition ability, science learning motivation, and scientific ability (Barcikowski and Robey, 1984; Gurevitch and Chester, 1986).

Time (pretest, posttest, and delayed posttest) was set as a within-subject variable. The variable was set as a group and the dependent variables were metacognition ability, science learning motivation, and scientific ability. As shown in **Table 3**, the variables' interaction effects between time and group were significant, which indicated that students had different developments on the selected variables. Therefore, a simple effect was performed.

Within the subject comparison, results indicated that the EG students' metacognition ability, science learning motivation, and science ability significantly increased in the posttest and delayed posttest more than in the pretest after the intervention programme. The posttest and delayed posttest scores of metacognition ability were higher than 3 on a five-point Likert scale, which indicated that the McR

TABLE 3 | Results of repeated measures analysis of variance.

		Time × group intervention effect		Time effect on each group	
Variables	**Group**	***F*-value**	**Partial η^2**	***F*-value**	**Partial η^2**
Knowledge	EG	539.22***	0.759	2077.82***	0.96
	CG			2.15	0.02
Experience	EG	161.16***	0.708	539.36***	0.85
	CG			0.62	0.01
Regulation	EG	11.09***	0.143	51.63***	0.34
	CG			0.72	0.01
Interest	EG	5.97**	0.083	12.12***	0.11
	CG			2.87	0.03
Competence	EG	4.10**	0.058	9.59***	0.09
	CG			<0.001	<0.001
Effort	EG	3.05**	0.077	11.02***	0.10
	CG			<0.001	<0.001
Evaluation	EG	13.14***	0.168	25.89***	0.21
	CG			0.66	0.01
Pressure	EG	3.69*	0.053	7.50**	0.07
	CG			0.68	0.01
Mathematical	EG	9.22***	0.122	73.01***	0.42
	CG			8.53***	0.08
Spatial	EG	6.90***	0.094	53.27***	0.35
	CG			4.10*	0.04

**p* < 0.05, ***p* < 0.01, ****p* < 0.001; EG, experimental group; CG, control group.*

intervention had a positive effect on the ADHD students' metacognition ability development. The largest change was found in the knowledge domain, followed by experience and regulation. Whilst no significant change was found in knowledge, experience, and regulation amongst the CG students, this result indicated that the intervention design had improved the EG students' metacognition ability across knowledge, experience, and regulation.

Significant time × group interaction effect was found in the science ability through a simple effect analysis. Both EG and CG scientific abilities had improved after receiving the intervention treatment. Specifically, the significant changes were found in EG [mathematical ($F = 73.01$, $p < 0.001$, partial $\eta^2 = 0.42$), spatial ($F = 53.27$, $p < 0.001$, partial $\eta^2 = 0.35$)] and CG [mathematical: ($F = 8.53$, $p < 0.001$, partial$\eta^2 = 0.08$); spatial ($F = 4.10$, $p < 0.05$, partial$\eta^2 = 0.04$)]. These results indicated that the astronomy knowledge curriculum had improved the students' scientific ability.

A repeated measures analysis of variance showed that the time × group interaction effect was significant. Simple effect analysis showed that only the EG students have significantly higher scores on interest ($F = 12.12$, $p < 0.001$, partial $\eta^2 = 0.11$), competence ($F = 9.59$, $p < 0.001$, partial $\eta^2 = 0.09$), effort ($F = 11.02$, $p < 0.001$, partial $\eta^2 = 0.10$), evaluation ($F = 25.89$, $p < 0.001$, partial $\eta^2 = 0.21$), and pressure ($F = 7.50$, $p < 0.01$, partial $\eta^2 = 0.07$) at the posttest and delayed posttest than in the pretest. These results indicated that the intervention treatment has enhanced the EG students' science learning motivation.

DISCUSSION

This study has confirmed that the instructional approach of McR is effective in enhancing the ADHD students' metacognition development, science knowledge learning motivation, and scientific ability development. This study also extends the content of DIM in astronomy knowledge education and shows that through McR interaction activities, ADHD learners can have higher metacognition abilities.

Effectiveness of Instructional Approach of Metacognitive Regulation on Metacognition Development

Through the McR intervention design, EG students performed significantly higher metacognition scores at the posttest and delayed posttest more than in the pretest. This result was consistent with previous studies, in which the intervention design could affect the students' metacognition development (Schunk, 2008; Hacker et al., 2019). This study was conducted under a school-based classroom teaching format. ADHD students in mainland China usually did not receive any special consideration from teachers and schools during formal school teaching and learning activities. This was a general feature for most Chinese schools. However, EG students in this study acquired great opportunities on metacognition awareness network construction. EG students have experienced initial learning process planning, evaluation, and monitoring, which satisfied the requirement of constantly monitoring the behavioural exposure and brief intervals between reinforcers (Arcia et al., 2000; DuPaul et al., 2011). This would be one key reason why the EG students performed significantly higher metacognition awareness after the intervention. The EG students' metacognition awareness was strengthened by the application of McR principles (planning, evaluation and monitoring). As a result, the level of ADHD students' attention problem would be reduced by the high-frequency interaction amongst ADHD students, teachers' instructional media, and group members' reminders.

Results have shown that metacognition has a network correlation amongst knowledge, experience, and regulation. Future studies could improve the students' metacognition performance *via* any subcategory of metacognition. Moreover, in astronomical education, it was more difficult to improve the regulation than the other two metacognition categories (knowledge and experience). This study also indicated that the group-based interactive learning format is an appropriate format for the ADHD students' metacognition awareness development.

Effectiveness of Metacognitive Regulation on Science Learning Motivation

This study showed that the EG students' science knowledge learning motivation had significantly improved after the intervention. These results were consistent with previous studies, which had shown a positive correlation between metacognition performance and learning motivation (de Boer et al., 2018; Bonfils et al., 2019). Self-determination theory (SDT, Deci and Ryan, 2008) suggested using *competence*, *autonomy,* and *social relatedness* to determine the learners' intrinsic learning motivation. There were two potential reasons to elaborate on the positive effect of McR on *interest*, *competence*, *effort*, *usefulness,* and *evaluation*. It should be the positive effect of metacognition development. McR provided the function of self-regulation during the astronomic learning process, which had a positive effect on *evaluation* and *usefulness* (de Boer et al., 2018; Bonfils et al., 2019). During astronomy knowledge acquisition, McR provided more cues and requirements to guide ADHD students on how to handle the learning target, wherein poor learners could be led to the right track. The feedback of the learning outcome for each astronomical knowledge node would contribute to the learners' *interest*, *effort,* and *competence* score, in which the McR had enlarged the ability of *competence* on science knowledge acquisition. Moreover, due to the three principles of McR, which were fully applied to each lesson, students became used to achieve the designed requirement automatically and the demands of *autonomy* of self-motivation improvement would be satisfied.

An alternative reason was the limitation of China's learning condition on the ADHD students' learning performance, which could be solved by the McR design. Due to the astronomical knowledge which usually contributed a small percentage in overall academic performance evaluation, students spent less time on astronomical subject exploration. The unique learning interest of activities might not be found in traditional learning curricula. In this study, through three principle applications of McR, the students paid more time on learning under a group-based learning mode. More immersion time in science knowledge would increase the opportunity to find science learning interests (de Boer et al., 2018). Moreover, the McR design not only encouraged ADHD students to experience the discovery learning process and cultivate their learning interest, but also reduced the restriction of tangible resource requirements (e.g., computers, appropriate learning materials) and intangible resources (e.g., high professionalism of teaching science). Students could perform at a higher proficiency in science, which might result in higher learning interest (de Boer et al., 2018). Results indicated that the key to improve the ADHD students' learning motivation was to satisfy the students' personal intrinsic requirement in learning.

Effectiveness of Metacognitive Regulation Design on Scientific Abilities Development

This study had shown that all students performed significantly higher scientific abilities at the posttest, echoing the suggestion that learning science could enhance the learners' scientific abilities (Lau and Roeser, 2002; Lin and Schunn, 2016). Previous studies had shown that science literacy exposure and relevant awareness activities (e.g., cooperate thinking activities) could enhance the learners' scientific abilities (Cherroret et al., 1992; Green et al., 2017). During astronomical knowledge learning, the curriculum not only provided science knowledge exposure to students, but also required students to think on the reason behind phenomena through various brainstorming activities. Moreover, the astronomical knowledge curriculum required learners to apply mathematical knowledge to solve problems and think about the relative locations amongst the celestial bodies, which provided a possibility for students to enhance their mathematical and spatial thinking abilities (De Backer et al., 2016; Hadwin et al., 2017). Results indicated that the astronomy learning context was an appropriate content to implement McR intervention to improve the students' scientific abilities, whilst McR intervention enhanced the students' awareness of monitor and control on scientific academic performances.

Limitations and Future Directions

This study did not distinguish the effect of each McR principle on metacognition awareness, science learning motivation, and scientific abilities. For future studies, it could further specify the McR principle into more detailed categories and test every detailed McR principle factors on students' academic achievement. Moreover, this study focussed on the effect of McR intervention on the ADHD students' astronomy knowledge acquisition and learning motivation. Whether the key concepts in astronomy or measures of the students' astronomy knowledge had an improvement remains unclear. For future studies, it should include more students' achievement variables as parameter to examine the intervention effect on these learning factors. Next, this study only tested the effectiveness of McR intervention on ADHD students. For other special education needs categories (e.g., ASD), the effect of McR on these students' academic performance remained unclear. For future studies, it should test the possibility of McR intervention on students with different special education needs. Finally, although the same instructor was trained separately regarding the two conditions, the instructor still may potentially carry over some intervention elements to the control condition, and the possible risk would affect the results of CG students' learning abilities. For future studies, it could take online experimental design to treat both EG and CG students at the same time, and the instruction to students should be fully controlled and presented online. The effect of online intervention format should be further explored.

CONCLUSION

This study provides evidence that the McR intervention design can improve the ADHD learners' scientific ability development, science knowledge learning, and overall metacognition development. Moreover, the dynamic interaction model is appropriate in providing sufficient guidelines for ADHD students to learn astronomical knowledge. The interaction activities amongst peers, teacher, and students are shown to benefit students' knowledge acquisition in astronomy.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Guangzhou University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

HYZ contributed data collection and dataset construction. YD contributed data analysis and draft writing. YKS contributed idea in research design and draft writing. JY contributed the revision on research design. CBY contributed the revision of data analysis and draft writing. JDW and WYD contributed draft writing. All authors contributed to the article and approved the submitted version.

FUNDING

This study was supported by the Guangdong Provincial Philosophy and Social Science Planning Youth Project Group. Project name: The Effects of Mastery Goal Intervention on Reading Anxiety and Reading Comprehension Project Number (2020WQNCX120).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.747961/full#supplementary-material

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frontiers in Psychology

ORIGINAL RESEARCH
published: 17 February 2022
doi: 10.3389/fpsyg.2022.720459

A Preliminary Study Comparing Pre-service and In-service School Principals' Self-Perception of Distributed Leadership Competencies in Relation to Teaching and Managerial Experience

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OPEN ACCESS

Edited by:
James Robbe Kraly,
Keene State College, United States

Reviewed by:
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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: 04 June 2021
Accepted: 24 January 2022
Published: 17 February 2022

Citation:
Cebrián G, Moraleda Á, Galán-Casado D and Andújar-Molina O (2022) A Preliminary Study Comparing Pre-service and In-service School Principals' Self-Perception of Distributed Leadership Competencies in Relation to Teaching and Managerial Experience. Front. Psychol. 13:720459. doi: 10.3389/fpsyg.2022.720459

So far little are the studies that have focussed on exploring school principals' self-conception of their distributed leadership competencies in relation to their managerial and teaching experience. To do so, an exploratory research was carried out with a sample of 163 pre-service and in-service school principals studying a Master's programme in School Management, Innovation and Leadership at a Spanish University. Data were obtained by using an *Ad hoc* questionnaire of 7 units of competence and 5 proficiency levels for each unit, based on an existing rubric to analyse students' self-conception of their development of leadership competencies. The findings of this preliminary study show statistically significant differences in the self-perception in all dimensions associated to Managerial Experience (ME) and Teaching Experience (TE) in schools. Study participants with ME showed statistically higher levels than those who had non-ME in four of seven dimensions: lead the school organisation, address the needs of the students, manage the organisation of the school organisation, and manage administrative work. Similar results were obtained in relation to TE versus non-TE were statistically significant differences are found in six dimensions: manage pedagogical and didactic resources, attend to the needs of students, manage didactic strategies, manage the organisation of the school organisation, manage the link between the school organisation and the community, and lead the school organisation. This study shows the importance of teaching and professional experience to acquire leadership competencies in education, therefore the school principal should also be a teacher. This preliminary study provides insights into the relevance of providing pre-service or in-service school principals with training and professional development programmes on sustainability distributed leadership that enable them to genuinely engage the school community, develop innovative pedagogies and lead the process of change toward building more sustainable schools.

Keywords: leadership, competencies, sustainability, school principals, distributed leadership

INTRODUCTION

Educational transformation toward sustainability also requires effective leadership, leaders who are capable of: translating vision into a comprehensive transformative change process; negotiating the change process with the different organisation agents and at the different institutional levels; assisting and including staff and the community; and being decisive and transparent (Fullan, 2003; Scott et al., 2012). Over the last decades, universities and academics have put efforts to develop sustainability competencies' frameworks and educational interventions, and to embed these mainly in higher education and teacher training (Wiek et al., 2011; Brundiers et al., 2021). However, the existing literature shows that further embedment of sustainability in pre-service teacher education, and specific training and professional development programmes on Education for Sustainable Development (ESD) for teachers and school principals are required to genuinely engage the school community in sustainability and to put in practice the leadership approaches necessary to build sustainable schools (Zachariou et al., 2013; Dyment and Hill, 2015; Ortega-Sánchez et al., 2020).

A wide agreement exists on distributed and transformative leadership as the leadership approaches required to create sustainable schools and to engage teachers and students in sustainability (Algan and Ummanel, 2019; Mogren and Gericke, 2019). Distributed leadership facilitates organisational change as it focuses on school leaders' democratic and equal participation and collaboration with all school members promoting a sustained organisational development over time (Harris, 2011; Spillane, 2012). Transformational or transformative leadership goes a step further in terms of critical thinking and worldviews' questioning, as if focuses on reframing existing mental models, attitudes and actions associated with sustainability (Byung-Jik et al., 2018). Despite the acknowledgement of the importance of leadership for achieving the integration of sustainability within schools, no agreed or common ESD leadership framework for schools or educational institutions exists and no research has documented this type of leadership in schools in a systematic way, without transcending good practices or specific case studies (Hallinger and Suriyankietkaew, 2018; Dries Verhelst et al., 2020).

Sustainability leadership research within the education arena is in its infancy (Lambert, 2012). Authors such as Hargreaves and Fink (2006), Davies (2009), and Hargreaves (2009) have developed theoretical frameworks and models to identify the principles and skills required for sustainability leadership. For example, Hargreaves and Fink (2006) built a model with seven key principles of sustainable leadership, namely: *depth* in learning and integrity; *length* referring to endurance and success over time; *breadth* of influence, promoting distribution rather than delegation; addressing *social justice*; developing environmental *diversity* having into account complexity and cohesion; development of human and material *resources* rather than depletion; and *conservation* and activist engagement with the environment through networks and alliances.

The importance of organisational conditions and a leadership approach oriented toward achieving sustainability has been highlighted in the literature (Kadji-Beltran et al., 2013). Therefore, recent literature has also focussed on conducting systematic literature reviews and developing theoretical frameworks on sustainability leadership, acknowledging its importance in creating sustained change and transformation within educational institutions. For example, Hallinger and Suriyankietkaew (2018) used science mapping tools to review 953 Scopus-indexed documents explicitly concerned with sustainable leadership and identified that most of research to date consists of case studies and single company quantitative surveys. Also, Müller et al. (2020) conducted a literature review to develop a conceptual framework, which offers four stages for the integration of sustainability and ESD in a school, identifying practical actions and management strategies. Dries Verhelst et al. (2020) identified the characteristics of the school facilitating ESD effectiveness through a literature review coming up with eight characteristics of an ESD-effective school organisation: sustainable leadership, school resources, pluralistic communication, supportive relations, collective efficacy, adaptability, democratic decision-making and shared vision.

According to Stevenson et al. (2014) sustainable leadership in schools implies: including ESD in the school vision to create holistic change; promoting ESD learning and understanding amongst school staff and teachers in their everyday practices; developing a professional learning community toward ESD; and promoting a whole-institution approach on ESD to facilitate its implementation in the different spheres of action. This implies the promotion of democratic decision-making, empowerment and collaboration amongst the school agents including students, teachers and the local community (Jackson, 2007). Therefore, sustainable leadership includes a leadership approach based on distribution and empowerment and creating whole-school approaches, which can be a challenge in the current education systems, which focus on control and accountability of school principals and teachers (Stevenson, 2007; Kadji-Beltran et al., 2013; Burns et al., 2015).

The existing studies in the education sector exploring school principals' knowledge, values and skills toward creating sustainable schools have mainly used questionnaires and mixed-method approaches. Algan and Ummanel (2019) used a mixed methods approach to research distributed leadership, organisational happiness and quality of work life in preschools, concluding that school leaders' behaviours showed the put in practice of distributed leadership. Also, Zachariou et al. (2013) designed a questionnaire to explore principals' self-reported competence for organising and implementing ESD in schools and their needs in education and training in order to effectively lead sustainable schools. The analysis revealed that school principals in Cyprus are poorly equipped for their new role as leaders of sustainable schools and agents of change, and focussed on exploring suitable forms, content and approaches for their professional development on ESD.

Different tools are being designed and utilised to assess learners' sustainability competencies. Questionnaires have been commonly used to assess or explore knowledge, attitudes, and behaviours toward sustainability (Kagawa, 2007; Biasutti and Frate, 2017). Qualitative tools such as rubrics, conceptual maps, reflexive diaries and interviews are also being developed as suitable instruments to assess sustainability competencies (García et al., 2017; Sandri et al., 2018). In a recently conducted literature review in this topic (Redman et al., 2021) three types of assessment are identified including self-assessment, observation, and test-based tools, where self-evaluation and assessment tools were underrepresented in relation to others.

While sustainability competencies frameworks have been developed for higher education and educators, no agreed or validated framework exists in relation to sustainability leadership competencies (Cebrián et al., 2020). The operationalisation of sustainability leadership competencies through the establishment of theoretical frameworks and assessment tools remains as a defiance. Therefore, further empirical research is needed through the usage of self-assessment tools to gain evidence on the self-perceived sustainability leadership competencies of school principals and influence of TE and ME that lead to the holistic transformation of educational institutions to embed ESD through distributed leadership and whole-school approaches.

So far little studies have documented in-service and pre-service school principals' perception in relation the educational leadership qualities and processes to build sustainable schools and how these are developed through TE and ME (Davis et al., 2005; Kadji-Beltran et al., 2013). Whilst they are envisioned as key change agents toward embedding sustainability within schools, for their privileged decision-making position and capacity to influence school organisational conditions (Jackson, 2007; Birney and Reed, 2009).

For this reason, are there statistically significant differences in the school principals' self-conception of their sustainability leadership competencies in relation to their ME and TE? Our hypothesis is that people with more TE and ME experience will show higher levels of self-perception of sustainable leadership competencies than people without that experience. This preliminary study was conceived as an exploratory research, where 163 pre-service and in-service school principals studying a Master's programme in School Management, Innovation and Leadership at a Spanish University responded to an *ad hoc* questionnaire.

Thus, the main objective of this research is to prove if there are statistically significant differences in the self-perception of their development of sustainable leadership competencies depending on whether they have TE or not, and in the same way with ME. Along with this, the complementary objective is to see if these differences are maintained or increased depending on the level of TE and ME.

MATERIALS AND METHODS

Sample

The sample population was composed of 163 pre-service and in-service school principals. With a convenience sampling, all participants were recruited as students of the Master's programme in School Management, Innovation and Leadership at Camilo José Cela University (Madrid, Spain) in the last three academic years. This master's programme is delivered online, and the students are from different subject areas, and include pre-service and in-service school principals. All the participants have an undergraduate degree related to education. The sample includes master's students who are professionals with previous experience and already working as school principals (in-service) or with no previous experience as school principals (pre-service). Students were asked whether they would like to complete an on-line questionnaire about their self-conceived leadership competencies.

An intentional non-probability sampling was used, based on voluntary participation, with ages ranging from 22 to 60 years of age [mean age 33.52 years and standard deviation (SD) of 7.4 years], with a sex distribution of 38.7% men and 61.3% women. The sample, see **Table 1**, was categorised, according to the Teaching Experience (TE) measured in years, differentiating, on the one hand, between the subjects who did have experience in and those who did not have it, and, on the other hand, between four levels of experience: none (0 years), low (1–4 years), medium (5–9 years) and wide (>9 years). Similarly, in the same table, it was done with the classification on Managerial Experience (ME) (previous professional experience as school principals) measured in years.

Instruments

An *Ad hoc* self-reporting questionnaire formed by 35 items (grouped in 7 dimensions) was designed to analyse pre-service and in-service school principals' perceptions –self-conception of the development of sustainability leadership competencies. The psychometric properties of the test had satisfactory values for the total score of the scale: internal consistency reliability,

TABLE 1 | Distribution of participants by levels of teaching and managerial experience.

		Level of teaching experience						
		Total	**No**	**Yes**	**None**	**Low**	**Medium**	**Wide**
Level of managerial experience	Total	163	31	132	31	40	41	51
	No	100	31	69	31	33	24	12
	Yes	63	0	63	0	7	17	39
	None	69	31	69	31	33	24	12
	Low	37	0	37	0	7	14	16
	Medium	14	0	14	0	0	2	12
	Wide	12	0	12	0	0	1	11

Cronbach's α value of 0.66. The instrument, a scale like Likert 1-5, has evaluated 7 of the central elements in terms of leadership and management of education centres such as: management of pedagogical and didactic resources, attention to the needs of students, management of didactic strategies, managing the organisation of the school organisation, managing the administrative work, managing the connection of the school organisation with the community, and leadership of the school organisation.

As our interest was to explore pre-service and in-service school principals' self-conception of their sustainability leadership competencies, we adapted an existing self-assessment tool on leadership competencies focussed on distributed leadership developed by Mejía Capaza (2015), which includes 7 units of competence and 5 levels of acquisition/proficiency levels for each unit: advanced, intermediate, basic, unsatisfactory and very unsatisfactory (**Figure 1**). Study participants had to self-rate their perceived level of proficiency for each unit of competence.

Design

An *ex post* facto research design has been developed in this preliminary study, the type of research that is applied when looking for the causes and awareness of a phenomenon that cannot occur because it has already happened (Campbell and Stanley, 1963; Fox, 1981; Kerlinger, 1987; Mateo, 1997).

Procedure

The main analysis focussed on assessing whether more experienced teachers and managers have a perception that their management and leadership intervention in schools increases over the years. The participants completed the questionnaire that included their informed consent in order to be involved in the study. They received no compensation for their participation. Their decision to participate was voluntary and anonymity and confidentiality were guaranteed with regard to data collection and processing. The study was carried out in accordance with the Declaration of Helsinki Ethics.

Data Analysis

With an anonymous and confidential data collection and treatment, the data analysis was performed using version 26.0 of the SPSS software. Prior to data exploration, the assumption of normality was verified by Kolmogorov-Smirnov (K-S) and the Shapiro-Wilk test. According to the results, non-parametric statistics were used for data analysis, specifically the comparison of Mann-Whitney *U* test and the Kruskal-Wallis *H* test, both with the rank-biserial correlation (r_{bis}) used as measured effect size estimator.

RESULTS

The descriptive statistics (mean and SD) of the dimensions, differentiating no/yes and none/low/medium/wide, are shown in **Table 2** for TE, and in **Table 3** for ME.

As the descriptive statistics show, in all dimensions, whether on TE or on ME, the average values are higher if they have

Competence unit	PROFICIENCY LEVELS				
	Advanced level	Intermediate level	Basic level	Unsatisfactory level	Very unsatisfactory level
Manages pedagogical and didactic resources	Manages visual materials (books, magazines,..), auditory (radio, spoken word, cinema) and audiovisual (computer presentation, video, cinema, internet, chat).	Integrally manages visual materials (books, magazines,...), and auditory materials (radio, spoken word, cinema), but only partially audiovisual materials (computer presentation, video, cinema, internet, chat).	Integrally manages visual materials (books, magazines,..), but only partially the auditory (radio, spoken word, cinema), and audiovisual materials (computer presentation, video, cinema, internet, chat).	Partially manages the visual materials (books, magazines,...), auditory (radio, spoken word, cinema) and audiovisual (computer presentation, video, cinema, internet, chat)	It partially manages the visual materials (books, magazines, PC ...), and auditory materials (radio, spoken word, cinema).
Addresses the needs of students	Integrally manages the development of tutorials and educational guidance, and the attention to academic, personal, and family problems of students.	Fully manages the development of tutorials and educational guidance, but the academic, personal, and family problems of students are only partially managed.	Fully manages the development of the tutorials, but the educational orientation, and the academic, personal, and family problems of students are partially managed.	Partially manages the development of tutorials, as well as educational guidance, and academic, personal, and family problems of students.	Partially manages the development of tutorials, as well as educational guidance.
Manages didactic strategies	Collaborates with teachers to implement student-centered, teacher-centered, and team learning approaches.	Fully collaborates with teachers to implement student-centered approaches, teacher-centered approaches, but only partially in team learning approaches.	Fully collaborates with teachers to implement student-centered approaches, but only partially in teacher-centered and team learning approaches.	Partially collaborates with teachers to implement student-centered, teacher-centered, and team learning approaches.	Partially collaborates with teachers to implement student- and teacher-centered approaches.
Manages the organisation of the school organisation	Manages the organization of teachers, students, parents, and administrative and support staff.	Integrally manages the organization of teachers, students, and parents, but does not manage the organisation of administrative and support staff.	Integrally manages the organization of teachers, and students, but does not manage the organisation of parents, administrative and support staff.	Partially manages the organization of teachers, students, parents, and administrative and support staff.	Partially manages the organization of teachers, students, and parents.
Manages administrative work	Manages human and economic resources and is also permanently accountable to the educational community.	Manages the human and economic resources and is sporadically accountable to the educational community.	Manages human and economic resources, but is not accountable to the educational community.	Partially manages the human and economic resources, but is not accountable to the educational community.	Does not manage the human and economic resources of the school.
Manages the link between the school organisation and the community	Manages relationships with community organizations, to develop projects that start from them, and help strengthen the link school-community, as well as the training of students.	Manages relationships exclusively with parents and with higher education authorities, to develop school projects that help strengthen the link school-community, as well as the training of students.	Manages permanent relationships with parents, but partially with higher education authorities, to develop school projects that help strengthen the link school-community, as well as the training of students.	Manages relationships with small groups of parents, to develop school projects that help strengthen the training of students, as well as the links with the community.	Sporadically manages relationships with groups of parents, to develop school projects to improve the training of students, as well as link with the community.
Leads the school organisation	Manages educational processes based on dialogue, communication, tolerance and the application of institutional regulations, for the resolution of conflicts and the development of school activities in line with the planning carried out.	Manages educational processes based on dialogue, communication, tolerance and partially applies the institutional regulations, for the resolution of conflicts and the development of school activities in line with the planning carried out.	Manages the educational processes from the exercise of power granted by the institutional regulations, for the resolution of conflicts and the development of school activities in accordance with the planning carried out.	Manages the educational processes from the exercise of power in a discretionary manner, for the resolution of conflicts and the development of school activities in accordance with the planning carried out.	Manages the educational processes based on the interests of the pressure groups in the school, to resolve conflicts and develop school activities in line with the planning carried out.

FIGURE 1 | Competence units and proficiency levels of distributed leadership competencies' framework. Adapted from Mejía Capaza (2015).

TABLE 2 | Descriptive statistics (Mean and SD) by dimensions based on teaching experience.

	No		Yes		None		Low		Medium		Wide	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Manages pedagogical and didactic resources	3.55	1.12	4.14	0.98	3.55	1.12	3.90	1.13	4.15	1.04	4.31	0.76
Addresses the needs of students	3.58	1.18	4.25	0.94	3.58	1.18	3.98	1.05	4.24	1.07	4.47	0.67
Manages didactic strategies	3.29	1.16	4.01	0.93	3.29	1.16	3.85	1.00	4.02	1.01	4.12	0.79
Manages the organisation of the school organisation	2.97	1.20	3.33	1.37	2.97	1.20	2.75	1.37	3.34	1.41	3.76	1.19
Manages administrative work	2.61	1.23	2.99	1.50	2.61	1.23	2.68	1.42	2.98	1.62	3.25	1.43
Manages the link between the school organisation and the community	2.87	1.23	3.50	1.24	2.87	1.23	3.15	1.29	3.49	1.34	3.78	1.06
Leads the school organisation	2.97	1.02	3.95	1.13	2.97	1.02	3.65	1.27	3.71	1.19	4.39	0.80

TABLE 3 | Descriptive statistics (Mean and SD) by dimensions based on managerial experience.

	No		Yes		None		Low		Medium		Wide	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Manages pedagogical and didactic resources	3.97	1.07	4.11	0.97	3.97	1.07	3.97	1.07	4.21	0.70	4.42	0.90
Addresses the needs of students	3.99	1.09	4.33	0.88	3.99	1.09	4.22	1.00	4.50	0.65	4.50	0.67
Manages didactic strategies	3.80	1.05	3.98	0.94	3.80	1.05	4.00	0.97	4.07	0.62	3.83	1.19
Manages the organisation of the school organisation	2.90	1.34	3.83	1.14	2.90	1.34	3.59	1.19	3.86	1.10	4.50	0.80
Manages administrative work	2.64	1.33	3.37	1.54	2.64	1.33	3.24	1.67	3.43	1.45	3.67	1.23
Manages the link between the school organisation and the community	3.24	1.30	3.60	1.17	3.24	1.30	3.51	1.30	3.64	0.74	3.83	1.19
Leads the school organisation	3.44	1.20	4.29	0.92	3.44	1.20	4.19	1.08	4.21	0.70	4.67	0.49

TABLE 4 | Results of Mann-Whitney *U* test teaching experience vs. no teaching experience in dimensions.

	Teaching experience	*N*	Mean rank	Sum of ranks	*U*	*P*	r_{bis}
Manages pedagogical and didactic resources	No	31	61.95	1920.50	1424.50	0.005*	0.270
	Yes	132	86.71	11445.50			
Addresses the needs of students	No	31	60.26	1868.00	1372.00	0.002*	0.300
	Yes	132	87.11	11498.00			
Manages didactic strategies	No	31	58.81	1823.00	1327.00	0.001*	0.324
	Yes	132	87.45	11543.00			
Manages the organisation of the school organisation	No	31	70.60	2188.50	1692.50	0.126	0.139
	Yes	132	84.68	11177.50			
Manages administrative work	No	31	72.06	2234.00	1738.00	0.182	0.137
	Yes	132	84.33	11132.00			
Manages the link between the school organisation and the community	No	31	63.48	1968.00	1472.00	0.013*	0.247
	Yes	132	86.35	11398.00			
Leads the school organisation	No	31	48.56	1505.50	1009.50	0.000*	0.414
	Yes	132	89.85	11860.50			

*Significations $p < 0.05$.

experience, which also always increases over the years. In relation to the aim of exploring if experienced teachers and school principals have a perception that their management and leadership intervention in schools increases over time, a non-parametric comparison was made using the Mann-Whitney *U* test.

Regarding the TE, we found statistically significant differences in 5 of the 7 dimensions, with moderate effect size ($r_{bis} = 0.300$), always with better mean rank in the people with such experience. In particular, the differences are significant in the following dimensions: manages pedagogical and didactic resources ($p = 0.005$, $r_{bis} = 0.270$), addresses the needs of students ($p = 0.002$, $r_{bis} = 0.300$), manages didactic strategies ($p = 0.001$, $r_{bis} = 0.324$), manages the link between the school organisation and the community ($p = 0.013$, $r_{bis} = 0.247$), and leads the school organisation ($p = 0.000$, $r_{bis} = 0.414$). The results are provided in **Table 4** for TE.

In the same way, regarding the management experience, statistically significant differences were found, with low effect size ($r_{bis} = 0.100$), always with better scores in the experienced subjects, in 4 of the 7 dimensions: addresses the needs of students ($p = 0.048$, $r_{bis} = 0.169$), manages the organisation of the school organisation ($p = 0.000$, $r_{bis} = 0.350$), manages administrative work ($p = 0.002$, $r_{bis} = 0.246$), and leads the school organisation

($p = 0.000$, $r_{bis} = 0.369$). The results are provided in **Table 5** for managerial experience.

To complement these results, the hypothesis contrast was supplemented by categorising into four levels (None/Low/Medium/Wide) of TE and ME, using the non-parametric comparison of the Kruskal-Wallis *H* test, which confirmed the vast majority of results.

In the case of TE, see **Table 6**, it increases the statistically significant differences to 6 of 7 dimensions. Only in dimension manages administrative work, no significant differences are

TABLE 5 | Results of Mann-Whitney *U* test managerial experience vs. no managerial experience in dimensions.

	Managerial experience	N	Mean rank	Sum of ranks	U	P	r_{bis}
Manages pedagogical and didactic resources	No	100	79.99	7998.50	2948.50	0.467	0.068
	Yes	63	85.20	5367.50			
Addresses the needs of students	No	100	76.61	7660.50	2610.50	0.048*	0.169
	Yes	63	90.56	5705.50			
Manages didactic strategies	No	100	79.23	7922.50	2872.50	0.321	0.090
	Yes	63	86.40	5443.50			
Manages the organisation of the school organisation	No	100	69.68	6967.50	1917.50	0.000*	0.350
	Yes	63	101.56	6398.50			
Manages administrative work	No	100	72.94	7294.00	2244.00	0.002*	0.246
	Yes	63	96.38	6072.00			
Manages the link between the school organisation and the community	No	100	76.94	7694.00	2644.00	0.076	0.144
	Yes	63	90.03	5672.00			
Leads the school organisation	No	100	68.67	6866.50	1816.50	0.000*	0.369
	Yes	63	103.17	6499.50			

Significations $p < 0.05$.

TABLE 6 | Results of Kruskal-Wallis *H* test level of teaching experience in dimensions.

	Teaching experience	N	Mean rank	H	df	P	r_{bis}
Manages pedagogical and didactic resources	None	31	61.95	10.342	3	0.016*	0.215
	Low	40	77.65				
	Medium	41	88.11				
	Wide	51	92.69				
Addresses the needs of students	None	31	60.26	14.432	3	0.002*	0.267
	Low	40	74.48				
	Medium	41	89.62				
	Wide	51	94.99				
Manages didactic strategies	None	31	58.81	11.594	3	0.009*	0.232
	Low	40	80.50				
	Medium	41	89.22				
	Wide	51	91.47				
Manages the organisation of the school organisation	None	31	70.60	15.029	3	0.002*	0.274
	Low	40	64.99				
	Medium	41	85.27				
	Wide	51	99.65				
Manages administrative work	None	31	72.06	5.414	3	0.144	0.123
	Low	40	74.01				
	Medium	41	84.16				
	Wide	51	92.57				
Manages the link between the school organisation and the community	None	31	63.48	11.732	3	0.008*	0.235
	Low	40	73.74				
	Medium	41	86.04				
	Wide	51	96.49				
Leads the school organisation	None	31	48.56	33.366	3	0.000*	0.436
	Low	40	78.31				
	Medium	41	79.41				
	Wide	51	107.29				

Significations $p < 0.05$.

found, in the rest there were with low effect size (r_{bis} = 0.100): manages pedagogical and didactic resources (p = 0.016, r_{bis} = 0.215), addresses the needs of students (p = 0.002, r_{bis} = 0.267), manages didactic strategies (p = 0.009, r_{bis} = 0.232), manages the organisation of the school organisation (p = 0.002, r_{bis} = 0.274), manages the link between the school organisation and the community (p = 0.008, r_{bis} = 0.235), and leads the school organisation (p = 0.000, r_{bis} = 0.436). As already mentioned, and can be seen in the mean ranks, in all dimensions the trend over the years is upward, that is, a greater self-perception.

In turn, regarding the ME, differentiated by the four levels, see **Table 7**, statistically significant differences are maintained in 3 of the 7 dimensions with low effect size (r_{bis} = 0.100), always with higher self-perceptions when there is more experience. The dimensions are manages the organisation of the school organisation (p = 0.000, r_{bis} = 0.355), manages administrative work (p = 0.013, r_{bis} = 0.221), and leads the school organisation (p = 0.000, r_{bis} = 0.367).

From an overview, putting together the four analyses carried out previously, the general results of this research reflect statistically significant differences in the self-perception of participation in all dimensions, having higher values in the participants with more TE and ME.

DISCUSSION

The results of this preliminary study are in line with previous studies such as the one carried out by Coggins and McGovern (2014), where it was concluded that educational leadership significantly contributes to the improvement of the outcomes of teaching and learning processes, also empowering teachers to formulate improvements to increase the effectiveness of the learning environment and student tracking. Another study conducted by Ross and Cozzens (2016) reinforces this premise, highlighting the importance of leadership support when assessing the diversity of teachers' ideas and opinions. In turn, the most effective school principals from a leadership-centred approach influence the school climate and culture through teacher collaboration and professional development (Louis et al., 2010). Along the same lines, previous studies have shown that educational leaders must recognise and assume a shared responsibility that goes beyond the intellectual and educational development of students, putting in place a real commitment to favour and focus on their personal, social physical and emotional development (Arhipova et al., 2018; Ghirmai Jambo and Hongde, 2020). Likewise, leadership must be understood as a compendium between the characteristics or

TABLE 7 | Results of Kruskal-Wallis *H* test level of managerial experience in dimensions.

	Managerial experience	*N*	Mean Rank	*H*	df	*P*	r_{bis}
Manages pedagogical and didactic resources	None	100	79.99	2.333	3	0.506	0.063
	Low	37	80.00				
	Medium	14	86.39				
	Wide	12	99.83				
Addresses the needs of students	None	100	76.61	4.635	3	0.201	0.100
	Low	37	86.57				
	Medium	14	96.11				
	Wide	12	96.42				
Manages didactic strategies	None	100	79.23	1.152	3	0.764	0.111
	Low	37	87.41				
	Medium	14	87.86				
	Wide	12	81.63				
Manages the organisation of the school organisation	None	100	69.68	23.095	3	0.000*	0.355
	Low	37	93.22				
	Medium	14	102.68				
	Wide	12	126.00				
Manages administrative work	None	100	72.94	10.794	3	0.013*	0.221
	Low	37	92.53				
	Medium	14	98.43				
	Wide	12	105.88				
Manages the link between the school organisation and the community	None	100	76.94	3.770	3	0.287	0.071
	Low	37	87.28				
	Medium	14	89.32				
	Wide	12	99.33				
Leads the school organisation	None	100	68.67	24.591	3	0.000*	0.367
	Low	37	100.34				
	Medium	14	96.50				
	Wide	12	119.67				

**Significations $p < 0.05$.*

personality traits and the specific skills for its execution and development (Amanchukwu et al., 2015). This implies not only a specific training and professional development programmes, but also the mobilisation of several intra- and inter-personal competencies to understand and act on the educational needs present in the school.

Although there are studies such as the one developed by Pont et al. (2008), where it is stated that the practice of school leadership requires specific skills and competencies that may not have been developed exclusively with TE, the results of this study and the current conditions of systemic change within educational environments require school principals' holistic understanding and specific competencies, that are gained through TE and ME. This is in line also with the study conducted by Ortega-Sánchez et al. (2020) that stressed the importance of developing school policies and teaching practice toward the inclusion of contemporary social problems in the curriculum at all education levels holistically.

Leadership competencies include the management of different processes such as educational, strategic, operational, interpersonal and intrapersonal together with reflective practice and continuous learning (Trakšelys et al., 2016). Precisely this continuous learning is a factor that is closely related to professional experience, which allows school principals to have the ability not only to manage external pedagogical axes for the benefit of student learning, but also the development of skills that involve listening and intervening in specific social circumstances, understanding individual subjectivities, and being resilient showing the ability to respond efficiently to unpredictable events (Leithwood et al., 2008; Male and Palaiologou, 2015). These are achieved through the professional experience and knowing the functioning, characteristics and needs of the recipients of the educational processes.

The findings of this study are in line with previous authors such as Escamilla (2006), who affirms that school principals are trained and developed through specific leadership training courses, and also nurtured from their role as teachers and with the daily practice and the experience gained in the school management over the years. These ideas are complemented by Boliìvar (2011), who highlights that the managerial experience and real practice have a critical role play in helping school leaders develop leadership competencies. Davis et al. (2005) also emphasise the importance of applying skills, knowledge and problem solving in authentic environments to achieve an effective managerial and leadership role has also been highlighted. Therefore, as the results from this study show, having previous teaching experience and learning-by-doing through management experience is critical to the development of distributed leadership competencies amongst school principals that can in turn contribute to create more sustainable organisations.

CONCLUSION

The existing literature in the area of sustainability education clearly highlights the key role that school leaders play in creating sustainable schools and empowering individuals through education to promote active change agents for the social transformation of societies toward more sustainable, equitable and socially just patterns. This requires effective leaders that are capable of fostering distributed leadership within their organisations where equal participation and collaboration between all school members and stakeholder groups is required.

The aims of this research were to explore the school principals' self-perception of their development of distributed leadership competencies in relation to previous ME and TE that can lead to creating sustainable schools and embedding ESD holistically within organisations. The findings of this preliminary study clearly show statistically significant differences in relation to the self-perceived development of distributed leadership competencies and previous TE and ME. Therefore, this study shows the importance of professional experience to acquire distributed leadership competencies, therefore the school principal should also be a teacher.

This study provides insights into the relevance of providing pre-service and in-service school principals with training and professional development programmes on sustainability and distributed leadership that enable them to genuinely engage the school community in ESD, develop innovative pedagogies and lead the process of change toward building more sustainable schools.

However, this preliminary study has several limitations, such as the low knowledge of sociodemographic, and professional (ME and TE) variables of the sample. Also, the lack of knowledge of the socio anagraphical variables of the subjects involved, that could have influenced the results obtained. Therefore, the relationship between both should be explored in further empirical research. It should be taken into consideration that the findings of this research explain a specific reality and context in a determined moment, therefore, the influence of contextual, political, educational and socio-cultural factors need to be further explored through cross-sectional studies involving different regions and countries.

Also, further empirical research is needed, beyond the *ex post* facto design with a Likert self-reporting scale in a non-randomised sample, that allows conducting experimental and longitudinal studies with a validated instrument, in terms of reliability and validity (the questionnaire has not been validated through an expert judgement), and a higher sample and number of school principals involved to determine how these leadership competencies are acquired over time and the organisational conditions and factors influencing their development.

Based on the research conducted, the authors suggest 3 pathways for further research and practice that will enhance the development of distributed leadership competencies toward embedding sustainability within educational institutions:

- Conduct longitudinal and cross-sectional studies using summative, formative and self-assessment tools that provide evidence of the development of sustainability distributed leadership competencies as they develop over time and the influence that contextual and organisational factors have.

- Operationalise sustainability distributed leadership competencies as constructs in the design and development of statistically validated assessment tools that guarantee the reliability and quality of the results.
- Develop clear learning and professional development pathways for school principals and leaders through in-service and pre-service leadership professional development programmes oriented to the development of distributed leadership in schools toward sustainability.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Universidad Camilo José Cela. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

GC, ÁM, and DG-C contributed to conception and designed of the study. GC organised the database and wrote the first draft of the manuscript. ÁM performed the statistical analysis. GC, ÁM, DG-C, and OA-M wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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frontiers in Psychology

ORIGINAL RESEARCH
published: 21 February 2022
doi: 10.3389/fpsyg.2022.746445

The Mediating Role of Critical Thinking Abilities in the Relationship Between English as a Foreign Language Learners' Writing Performance and Their Language Learning Strategies

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OPEN ACCESS

Edited by:
Jin Su Jeong,
University of Extremadura, Spain

Reviewed by:
Luxin Yang,
Beijing Foreign Studies University, China
David Gonzalez-Gomez,
University of Extremadura, Spain

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Specialty section:
This article was submitted to Educational Psychology, a section of the journal Frontiers in Psychology

Received: *23 July 2021*
Accepted: *24 January 2022*
Published: *21 February 2022*

Citation:
Esmaeil Nejad M, Izadpanah S, Namaziandost E and Rahbar B (2022) The Mediating Role of Critical Thinking Abilities in the Relationship Between English as a Foreign Language Learners' Writing Performance and Their Language Learning Strategies. Front. Psychol. 13:746445. doi: 10.3389/fpsyg.2022.746445

Recent developments in the field of education have led to a renewed interest in the mediating role of critical thinking abilities (CTA) in the relationship between language learning strategies and the intermediate English as a Foreign Language (EFL) learners' writing performance. Oxford Placement Test (OPT) was run to homogenize the participants, and 100 intermediate learners out of 235 were selected. Then, two valid questionnaires of Ricketts' Critical Thinking Disposition and Oxford's Strategy Inventory for Language Learning were administered. Having administered the questionnaires, the researchers asked the participants to sit for a writing test. The data collected from the questionnaires and as well as the scores of their writing performances were analyzed through SPSS (25.00). The results showed a significant relationship between (a) learning strategies and learners' writing performances, (b) the sub-sets of learning strategies and learners' writing performances, and (c) CTA and learners' learning strategies. However, CTA did not play a mediating role in the relationship between intermediate EFL learners' learning strategies and writing performance. Based on the results of the study, one might also conclude that strategies seemed to play a more important role in the performance of learners especially their writing performances. Therefore, this study had useful contributions for students, teachers, and curriculum designers. Findings of this research could assist teachers to be aware of learners' strategies in learning writing and help their students to be responsive to using learning strategies in their learning process and create a satisfactory learning context for using learning strategies. Therefore, learners were able to become independent and feel responsibility for their own learning. Secondly, curriculum developers could take advantage of the findings to include learning strategies training into the curriculum. As a result, students were able to use strategies in their learning process more easily and finally, the results might pave the way for improving the research findings.

Keywords: EFL learners, critical thinking, language learning strategies, mediating role, writing performance

INTRODUCTION

This study examined the relationships between writing performance and language learning strategies (cognitive, metacognitive, social, affective, memory-related, and compensation). It also intended to determine the relationship between intermediate English as a Foreign Language (EFL) learners' critical thinking abilities and their writing performances. There are some factors which could affect language learning strategies by learners. According to some researchers' different variables such as age, gender, language proficiency, motivation, anxiety, aptitude, and cultural background affect using language learning strategies by students (e.g., Berridge, 2018; Esteves et al., 2021). However, a quick review of the global literature shows that little attention is given to the role of critical thinking in learners' choice of learning strategies as well as their writing performances.

Recent developments in the field of critical thinking abilities have also led to a renewed interest in EFL learners' writing performance (Renatovna and Renatovna, 2021). It is becoming increasingly difficult to ignore the role of critical thinking abilities (Warsah et al., 2021). Recently, the focus of the teacher-oriented viewpoint has changed to a learner-centered perspective (Reshadi and Aidinlou, 2012; Al Sharadgah, 2014; Yaralı and Aytar, 2021). Learners are now in charge of their learning more than ever. In other words, more learners take more responsibility to make the best use of language learning strategies (LLSs) and be conscious of their own individual needs (Teng, 2020; Parra et al., 2021). New learning strategies are introduced to the learners to develop their personable attainments in the language learning process (Sutiani et al., 2021).

Learning strategies are made up of mental processes – thoughts or behaviors – that help learners understand, learn, or sustain new information (Panahandeh and Esfandiar, 2014; Jiang et al., 2021). The concept of learning strategies plays a crucial role in the study of second or foreign language learning. Even though many studies have been done to implement learning strategies, the idea of learning strategies is still obscure. Dörnyei and Skehan (2003), Rajaee Pitenoee et al. (2017), and Chang et al. (2021) assert that the opinion behind learning strategies has not been critically examined because the concepts and definitions have been inconsistent so far. Critical thinking abilities play a significant role in language learning and teaching. Choosing critical thinking abilities, among other skills and strategies, is to help students do writing performance difficulties and teachers who try to help do their students' writing performances.

In addition, few studies have been carried on to compare the learning strategies of cognitive, metacognitive, and social/affective, memory-related strategies with writing performances. Besides, no studies, to the best knowledge of the researchers, had ever embarked on investigating the mediating role of critical thinking abilities in the relationship between intermediate EFL learners' writing performance and their learning strategies. A quick review of the global literature shows that little attention is given to the role of critical thinking abilities in learners' choice of learning strategies and their writing performances.

In a nutshell, this study aimed to evaluate the mediating role of critical thinking abilities in the relationship between EFL learners' writing performance and their language learning strategies.

REVIEW OF LITERATURE

Learning Strategies and Writing Performance

Learning strategies are defined as "proceedings or stages used by a learner to comfort the attainment, storage, detection or use of information" (Rigney, 1978 cited in Aslan, 2009, p. 45). O'Malley and Chamot (1990) defined learning strategies as the particular thoughts or compartments that everybody uses to understand, learn, or maintain new information. On the other hand, Chamot (2004), Bagheri (2015), and Zarrinabadi et al. (2021) claim that learning strategies are the purposive thoughts and behavior that students take to earn a learning goal. More importantly, successful learners have their unique techniques to learn. Rubin (1975) and Stern (1975) have been the first scholars who analyze the idea of successful language learning. This idea makes us more curious to discover more about the nature of the learning and learning process. Consequently, the majority of the research performed until now has been focusing on the detection, explanation, and categorization of learning strategies (Pradhan and Das, 2021; Tran and Tran, 2021).

The relationship between language learning strategies (LLS) and writing performance (WP) has been the subject of much research over the last 20 years (Goudarzi et al., 2015; Wale and Bogale, 2021). According to Green and Oxford (1995), the picture is not crystal clear because a lot of research has focused on overall strategy use only and not considered individual strategy use or variations. In a study done by Saricoban and Saricaoglu (2008) in Turkey, it was found that compensation strategies had a positive correlation with academic achievement (p. 172) while affective strategies were negatively correlated. Students who used affective strategies were less successful than others. Griffiths (2004), in a study at a private language school in Auckland, found that "there was a significant relationship between strategy use and language proficiency" (p. 82). The study showed that the "Advanced students reported a higher average frequency of use of each strategy than did elementary students" (p. 78). These studies imply that we can raise levels of proficiency by teaching these strategies. These studies may not have shown a clear causality in any direction between language proficiency and strategy use; however, it can be logically concluded that there are significant relationships between the two.

According to Oxford (1990), learning strategies are categorized into direct and indirect strategies. Also, each category is divided into subcategories which are placed under the labels. Learners directly use direct strategies in the learning process to produce the target language. These strategies include memory strategies which are responsible for retrieving and storing information, cognitive strategies which learners use to process new information; and learners use compensation strategies to compensate for lack of enough knowledge in the target language (Goudarzi et al., 2015; García-Sánchez and García-Martín, 2021; Zarrinabadi et al., 2021). As Oxford (1990) states, these strategies assist students to be more independent, identify their learning strengths and weaknesses, and be self-reliant in their language learning process. Therefore, learning strategies help learners to become competent in using a language. Based on Oxford and Burry-Stock (1995), strategies are techniques or behaviors used unconsciously by learners to improve their understanding and use the target language. O'Malley and Chamot (1990) proposed a very comprehensive classification of learning strategies. Their tri-faceted classification is as follows:

1. Metacognitive strategies: It includes supervisory processes in planning for learning, supervising one's understanding and production, and assessing to what extent individuals have achieved a learning goal.
2. Cognitive strategies: Mentally speaking, manipulating the materials to be learned through interaction by visualizing mental pictures or connecting the material with the previously known items. Physically speaking, categorizing the things to be learned meaningfully or summarizing the essential items to be known.
3. Social-affective strategies: Learner's interact with others to look for help in learning, such as posing questions for cooperation or using some affective to control learning.

Critical Thinking Abilities and Writing Performance

In modern society, even in everyday life, people frequently need to deal with complicated public and political issues, make decisions, and solve problems (Bagheri, 2015; Zarrinabadi et al., 2021). To do this efficiently and effectively, citizens must evaluate critically what they see, hear, and read. Although a massive amount of printed material is available in all areas in the age of "information explosion," it is still easy to feel overwhelmed. But the information piled up on people's desks and in their minds is of no use due to the enormous amount of it. Thus, they need to read selectively and sort out the bits and pieces that are interesting and useful for them. To do so, strong critical reading and critical thinking skills are indispensable (Morgan and Shermis, 1994).

Writing is a complex process that needs much effort to be completed. Numerous researchers believe that writing is a skill that requires learning and practicing (Fathi et al., 2019; Neimaoui, 2019; Wale and Bogale, 2021). Also, Langan (1987), Reid (1993), and El-Freihat and Al-Shbeil (2021), note that writing is a craft skill that can be taught and learned. For effective writing in EFL classrooms, ELT practitioners (Badger and White, 2000; Paltridge, 2004; Rahayu, 2021) suggest three following approaches: product, process, and genre. According to Zamel (1983), Liu and Hansen (2002), and Indah (2017), the process approach focuses on the composing process, whereby writers express their notions as they attempt to transfer the meaning. According to Gabrielatos (2002) and Hall (2017), a product approach is a traditional approach, in which students are motivated to copy a model text while the genre approach is the newcomer and an outcome of the communicative language teaching approach. The readers are at the center of this approach since its readership must successfully accept it.

The word "writing" means the text in written form in the process of thinking, constructing, and coding language into such text (Tabibian and Heidari-Shahreza, 2016; Irzawati et al., 2021; Namaziandost et al., 2021). Since writing is one of the skills in first and second language learning, all skills have a relationship. As an instance, Harmer (1991), Rahimi and Karbalaei (2016), Taghinezhad et al. (2018), and Yan (2018) believe that one skill cannot be carried out without the other, and it is impossible to communicate without listening, and people seldom write without reading.

The relation between writing and thinking is that writing is thinking if one cannot think clearly, one cannot write clearly. Writing develops thinking skills. It improves the thinking process and contributes to the development of thinking skills because an individual has to clearly state ideas and lay out arguments in such a way as to cultivate higher order of thinking. Regarding the relationship between both, the Sapir-Whorf hypothesis (1956 in Errihani, 2012; Jiang et al., 2021; Wale and Bogale, 2021) is suggestive in the context of English as a Foreign Language as it contends that cognitive activity is determined by language. The cognitive activity can be reflected in written text and later be understood well by the audience determined by the strength of the language (Díaz Larenas et al., 2017; Rahayu, 2021). Consequently, the primary concern of second language (L2) writers is primarily on linguistics, as noted by Errihani (2012). Therefore, critical thinking ability reflects their linguistic skill represented by their writing, which reflects the background knowledge.

The Relationship Between Critical Thinking Abilities and Learning Strategies

Literature on the relationship between critical thinking and language learning strategies is not much. However, a number of studies have been conducted so far. In a survey conducted by Nikoopour et al. (2011), they surveyed the relationship between CTA and the use of LLS by Iranian language learners. Their findings reveal a significant correlation between direct and indirect LLS such as cognitive, meta-cognitive, and social with critical thinking. At the same time, no relationship was discovered between CTA and memory, compensation, and affective strategies. In another study by Ku (2009), they aimed to examine the role of meta-cognitive strategies in critical thinking. Based on the findings, "good critical thinkers" are more active in meta-cognitive activities.

Although critical thinking ability is not directly measurable and is not easy to teach, there is always a chance to enhance these strategies through deliberate teaching (Willingham, 2007; Nikoopour et al., 2011; Mosley et al., 2016). Learning strategies can develop and improve it (Loving and Wilson, 2000; Seymour et al., 2003). The teacher is responsible for its development (Choy and Cheah, 2009). Willingham (2007) stated that one of the fundamental purposes of education is to enable students to think critically, but this goal is incompetently met. As the 21st century is the age of information technology, critical thinking abilities are a crucial requirement to select and evaluate the reliability of the information (Grabau, 2007). Asian students lack the required skill as it is not commonly emphasized in schools (Egege and Kutieleh, 2004; Djiwandono, 2013). Learning activities have been used to develop the critical thinking skills of the learners for years. Literature suggests cooperative learning is very fruitful for developing students' social skills, language acquisition, and academic achievement and fostering critical thinking skills (Ghaith, 2003; Sadeghi, 2012). Students who learn through strategies have a chance to develop their thinking. Students' face-to-face interaction promotes critical thinking abilities (Fahim and Eslamdoost, 2014). Group discussions effectively stimulate and develop ideas, which is the first requirement of critical thinking abilities (Devi et al., 2015). The student's critical thinking abilities can be enhanced through cooperative learning. In collaborative learning, students have a chance to group discussion, evaluate and synthesize the information, and consider the solution as students are responsible for their learning. Cooperative learning promotes interaction among students, which helps develop critical thinking abilities (Devi et al., 2015; Mahmoodi and Dehghannezhad, 2015).

This study examined the relationships between writing performance and language learning strategies (cognitive, metacognitive, social, affective, memory-related, and compensation). This study also intended to determine the relationship between intermediate EFL learners' critical thinking abilities and their writing performances. Based on the analysis, one might also conclude that strategies seemed to play a more important role in learners' performance, especially their writing performances. Therefore, this study had valuable contributions for students, teachers, and curriculum designers.

All in all, reviewing the literature so far indicates that the impact of CTA on language skills and sub-skills has not received as much attention as warranted. Moreover, rare studies, if any, have been done in this regard Iranian context. Thus, to cover these gaps, the researchers aim to explore if CTA has any role in the relationship between language learning strategies and the intermediate EFL learners' writing performance. To this purpose, the following research questions were proposed:

1. Is there any significant relationship between intermediate EFL learners' learning strategies and their writing performances?
2. Is there any significant relationship between intermediate EFL learners' cognitive strategy (CS), metacognitive strategy (MS), social strategy (SS), affective strategy (AS), compensation strategy (CS), memory-related strategy (MS), and their writing performances?
3. Is there any significant relationship between intermediate EFL learners' critical thinking abilities and writing performances?
4. Is there any significant relationship between intermediate EFL learners' learning strategies and their critical thinking?
5. Does critical thinking ability play a mediating role in the relationship between intermediate EFL learners' learning strategies and writing performances?

MATERIALS AND METHODS

Participants

The participants of this study were 235 male and female Iranian EFL learners at different language institutes in Zanjan, Iran who were selected based on the convenience sampling method. Oxford Placement Test (OPT) was run to make the participants homogeneous, and 100 learners were selected as the final participants. According to the OPT, 37 people had advanced level scores and 98 people had elementary level scores who were excluded from the study. That is, low- and high-level average scores based on the OPT were summarized and included in the study [Mean (SD) = 37.5 $\pm$ 9.15]. The selected participants were all EFL intermediate learners at language institutes ranging from 18 to 35 years of age. More details about the participants can be seen in **Table 1**.

Instruments

In line with the purposes of this research, three instruments were used:

(1) OPT: To meet the purposes mentioned above, at first, a language skill test version 2, including 60 items matching cloze passages and multiple-choice questions were managed to sure the concord of the learners. The test items most focused on grammar and vocabulary. The participants were given 30 min to answer. Those learners whose scores fell between 30 and 39 were considered intermediate ones.

(2) Critical Thinking Dispositions Questionnaire (Ricketts, 2003)*:* Used to measure the intermediate EFL learners' critical thinking disposition. The questionnaire contained 33 statements on the Likert 5-point scale. The minimum mean and maximum scores that could be achieved were 33, 99, and 145. Three sub-components of the questionnaire are creativity with 11 sentences, sophistication with nine statements, and dedication with 13 statements. The Cronbach's alpha coefficients for the invention, sophistication, and commitment subcomponents are 0.64, 0.53, and 0.82, respectively. The reliability coefficient of the instrument was stated to be approximately 0.76 by PakMehr et al. (2010).

(3) Strategy Inventory for Language Learning Questionnaire (Oxford, 1990)*:* The following inventory included in this analysis was the Strategy Inventory for Language Learning

TABLE 1 | Demographic characteristics of the participants.

	Number	Age	Gender	Level of proficiency	First language
Participants	100	18–35	Males (50); Female (50)	Intermediate	Persian

(SILL) questionnaire used to classify LLS students. The SILL questionnaire was developed by Oxford (1990) and was used without alteration in this research. It comprised 50 items that included six types of LLSs: recall strategies, cognitive strategies, compensation strategies, metacognitive strategies, affective strategies, and social strategies. The questionnaire was a 5-point Likert scale that ranged from 1 (*Never or almost never true of me*), 2 (*Usually not true of me*), 3 (*somewhat true of me*), 2 (*usually true of me*), and 5 (*always or almost always true of me*).

Writing Performance

In order to measure the writing performance of the participants, they were asked to sit for a writing exam in the class. An argumentative topic titled "Using *a computer every day can have more negative than positive effects on your children. Do you agree or disagree?*" was introduced to the intermediate learners to compose a well-formed essay.

There were many different types of rubrics in the literature for assessing writings. One of the appropriate scales for rating the writing of learners was Cooper's (1997) scale. This rubric includes different criteria for assessing learning writing performance. Cooper's (1997) checklist is shown below:

Rating scales covered "Task Achievement," "Coherence and Cohesion," "Lexical Resource," and "Grammatical Range and Accuracy."

In the holistic grading method, as illustrated in **Figure 1**, the reader assigns a single score from 0 to 6 (0, 1, 2, 3, 4, 5, or 6) to an essay based on overall writing quality.

Each essay was scored based on the four scales of "Task Achievement," "Coherence and Cohesion," "Lexical Resource," and "Grammatical Range," and "Accuracy." In the end, the average of the five scales showed the last score given to any essay by each rater. Subsequently, the average score given by the two raters represented the writer's final score.

Procedure

In order to obtain fair answers to the study questions alluded to above, the following steps have been taken. First, the OPT was spread among EFL students from different institutes in Zanjan to assess the participants' homogeneity and choose advanced language learners. One hundred participants receiving scores from 30 to 39 were selected as the final sample. Second, the Critical Thinking Dispositions Questionnaire (CTDQ) (Ricketts, 2003) was distributed among the intermediate EFL learners. The CTDQ questionnaire included 33 Likert items. Moreover, the Approach Inventory questionnaire (Oxford, 1990) for language learning was administered to the selected intermediate learners. It was a 50-item questionnaire with a 5-point Likert scale ranging from 1 (never or almost never applies to me) to 5 (always or almost always applies to me).

Afterward, the participants were asked to sit for an essay writing test. An argumentative topic entitled "Using *a computer every day can have more negative than positive effects on your children. Do you agree or disagree?*" was introduced to the intermediate earners to compose a well-formed essay on. Two raters scored all the essays based on Cooper's (1997) rubric scale. The average score given by the two raters accounted for the learners' final writing score. In the end, the scores of their writing performances and the data gathered from the SILL and Critical Thinking Disposition questionnaires were put into SPSS version 25 to be calculated.

The study was an ex-post-facto design since there were no treatments at all. Having collected the results, the researchers recorded the scores in computer files for statistical analysis using the Statistical Package for the Social Sciences (SPSS) version 25.0. After homogenizing the students as intermediate, to measure the relationship between the variables (SILL and SILL components and writing performance), since the normality was met, seven Pearson correlation tests were conducted. In addition, another Pearson correlation test was run to find if there was

Cooper's Classification of Writing Rating Scale

Aspects	Descriptions of performance	Scores 0-6
Task Achievement		
Coherence and Cohesion		
Lexical Resource		
Grammatical Range		
Accuracy		

FIGURE 1 | Cooper's classification of writing rating scale. 6, outstanding; 5, very good; 4, good; 3, adequate; 2, less than adequate; 1, poor; 0, no substantive response.

a significant relationship between critical thinking abilities and writing performance. Furthermore, the Pearson correlation test was conducted to measure the relationship between learning strategies and intermediate EFL learners' critical thinking abilities as a whole. Finally, to figure out whether critical thinking abilities would play a mediating role in the relationship between learning strategies and writing performance, the Sobel test was used.

RESULTS

This study aimed at investigating the mediating role of critical thinking abilities in the relationship between learning strategies, including cognitive, meta-cognitive, memory-related, compensation, social, and affective strategies, and intermediate EFL learners' writing performance. First of all, it was necessary to check the normality distribution. Thus, a One-Sample Kolmogorov–Smirnov Test was run.

Based on the statistics in **Table 2**, all the *p*-values are higher than 0.05 ($p > 0.05$), it, thus, can be concluded that all the variables benefit from a normal distribution. Accordingly, the researchers are allowed to utilize parametric analysis of the data. The research questions of this study are answered in this part. The related descriptive analysis of all variables will be discussed before defining the inferential analysis:

As **Table 3** shows, regarding the number of participants ($N = 100$), the mean and the SD of writing performance are 4.22 and 3.27, respectively. The means for critical thinking abilities and learning strategies are 112.56 and 195.20, respectively.

First of all, regarding the relationship between intermediate EFL learners' learning strategies and their writing performances, the results of Pearson correlation displayed in **Table 4** [$r(98) = 0.865$, $p < 0.05$ representing a large effect size] it can be concluded that there was a significant relationship between learning strategies and writing performance.

Moreover, considering the relationship between intermediate EFL learners' CS, MS, SS, AS, CS, MS, and their writing performances, a Pearson correlation was run, which shows that there was a significant relationship between EFL learners' CS, MS, SS, AS, CS, MS, and their writing performance ($p < 0.05$) (**Table 5**).

TABLE 2 | Normality tests: One-sample Kolmogorov–Smirnov test.

Variables	Sig.	Decision	Test result
Total strategies	0.163	The null hypothesis is accepted	Distribution is normal
CS	0.097	The null hypothesis is accepted	Distribution is normal
MS	0.189	The null hypothesis is accepted	Distribution is normal
SS	0.20	The null hypothesis is accepted	Distribution is normal
AS	0.20	The null hypothesis is accepted	Distribution is normal
CS	0.095	The null hypothesis is accepted	Distribution is normal
MS	0.183	The null hypothesis is accepted	Distribution is normal
CT	0.20	The null hypothesis is accepted	Distribution is normal
Writing performances	0.112	The null hypothesis is accepted	Distribution is normal

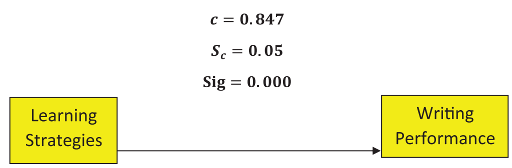
TABLE 3 | Descriptive statistics of the research variables.

	N	Minimum	Maximum	Mean	Std. deviation
Total strategies	100	60.00	235.00	195.20	3.21
CS	100	21.00	65.00	56.25	2.36
MS	100	13.00	42.00	32.28	1.62
SS	100	8.00	27.00	23.65	2.39
AS	100	9.00	28.00	25.45	2.85
CS	100	8.00	25.00	22.91	5.17
MS	100	11.00	42.00	34.62	3.09
CT	100	45.00	136.00	112.56	2.99
Writing performances	100	2.00	6.00	4.22	3.27

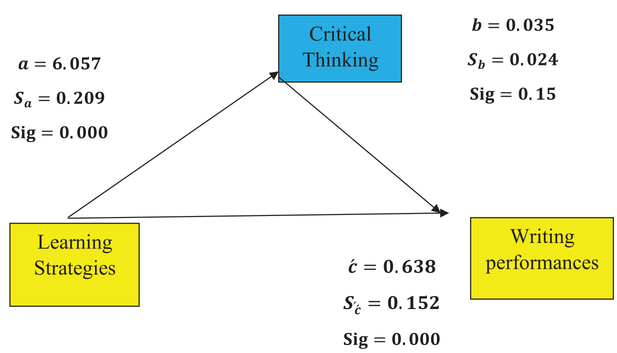
In addition, to check the relationship between intermediate EFL learners' critical thinking abilities and their writing performances, the Pearson correlation analysis in **Table 6** [$r(98) = 0.843$, $p < 0.05$] indicates that the relationship between critical thinking abilities and writing performance was significant.

Furthermore, regarding the relationship between intermediate EFL learners' learning strategies and their critical thinking abilities, Pearson correlation results show a significant relationship ($p < 0.05$) (**Table 7**).

Lastly, considering the relationship between intermediate EFL learners' learning strategies and their writing performances, the following conceptual model was used to illustrate the direct impact of learning strategies on writing performance.



As it is shown, the direct impact of learning strategies on writing performance is 0.847, with the SD of 0.05. Regarding the fact that $p < 0.05$, it is believed that direct impact is significant. The conceptual model below shows the mediating role of critical thinking abilities in the relationship between learning strategies and writing performance:



As depicted above, the impact of the mediating role of CTA on writing performance was 0.035, with the SD of 0.024. Since $p > 0.05$, it is concluded that the impact of CTA on writing performance is not significant. As also illustrated above, the impact of learning strategies on CTA is 6.057, with the SD of

TABLE 4 | Pearson correlation: Learning strategies with writing performances.

		Learning strategies
Writing performances	Pearson correlation	0.865
	Sig. (two-tailed)	0.000
	N	100

TABLE 5 | Pearson correlation: CS, MS, SS, AS, CS, and MS with writing performances.

		CS
Writing performances	Pearson correlation	0.668
	Sig. (two-tailed)	0.000
	N	100
		MS
Writing performances	Pearson correlation	0.872
	Sig. (two-tailed)	0.000
	N	100
		SS
Writing performances	Pearson correlation	0.775
	Sig. (two-tailed)	0.000
	N	100
		AS
Writing performances	Pearson correlation	0.790
	Sig. (two-tailed)	0.000
	N	100
		CS
Writing performances	Pearson correlation	0.767
	Sig. (two-tailed)	0.000
	N	100
		MS
Writing performances	Pearson correlation	0.765
	Sig. (two-tailed)	0.000
	N	100

0.209. Because $p < 0.05$, it is concluded that the impact of learning strategies on CT is significant. Besides, the impact of learning strategies on writing performance, with the mediating role of CTA, is 0.638, SD = 0.152. Regarding the p-value, which is less than 0.05 ($p < 0.05$), it is concluded that the impact of learning strategies on writing performance, with the mediating role of CTA, is not significant because the Z value of the Sobel test is 1.46 and $p > 0.14$. Thus, CTA does not play a mediating role in the relationship between learning strategies and writing performance.

DISCUSSION

As stated earlier, this study made an effort to find answers to all research questions concerning the relationship between the three variables CTA, learning strategies, and writing efficiency. Reasonable methods have been used to obtain the answers needed for each question. The study found that high CTA students outperformed low CTA students. Cognitive and metacognitive techniques are not independent; they operate together as learners undertake the process of writing.

TABLE 6 | Pearson correlation: CTA with writing performances.

		CTA
Writing performances	Pearson correlation	0.843
	Sig. (two-tailed)	0.000
	N	100

TABLE 7 | Pearson correlation: CTA with learning strategies.

		Learning strategies
CT	Pearson correlation	0.946
	Sig. (two-tailed)	0.000
	N	100

Both learning strategies and CTA played an essential role in students' writing performance. CTA is highly related to writing performance, and it was proved those with high CTA did better in their writing performance, especially when the subject was a bit controversial. Furthermore, it was shown that utilizing learning strategies would improve learners' writing performance. In other words, the more use of strategies, the better scores in writing performance.

As seen before, the relationship between intermediate EFL learners' learning strategies and their writing performance was significant. In addition, the relationships between intermediate EFL learners' learning strategies subsets, including cognitive, metacognitive, affective, social, memory-related, and compensation strategies, and their writing strategies were all significant, meaning all the six subsets were significantly correlated with writing performances. The result of this study is in line with the studies done by Chamot (2004), Berridge (2018), Al-Jarrah et al. (2019), Teng (2020), Chang et al. (2021), and Parra et al. (2021) in that metacognitive strategies together with its subsets of planning, organizing, and evaluating strategies are related to EFL learners' writing performances. Besides, this study also confirmed the findings of Pradhan and Das (2021) and Tran and Tran (2021) that there was a positive correlation between English academic achievement and metacognition. In harmony with Teng (2020) and Jiang et al. (2021), metacognitive strategies could yield the highest mean scores of EFL learners' writing performances.

In congruence with the finding of Yan (2018), García-Sánchez and García-Martín (2021), and Parra et al. (2021), this study showed a positive correlation between cognitive and metacognitive strategies of learners with their writing performances. Compatible with the findings of Díaz Larenas et al. (2017) and Rahayu (2021), this study also showed that metacognitive and cognitive strategies would benefit EFL learners' writing performance.

As Díaz Rodríguez (2014) asserts, this study also illustrated that cognitive and metacognitive strategies are not independent from one another; they work together while the learner is performing the task of writing. Following Rajaee Pitenoee et al.'s (2017) outcome, cognitive and metacognitive strategies would affect Iranian intermediate EFL learners' writing performance. Meanwhile, in line with Azizi et al. (2017), this study also confirmed that metacognitive strategies would contribute to higher proficiency in writing. In addition, as Tabrizi and Rajaee (2016) and Tran and Tran (2021) put forward, this study also concluded that cognitive and metacognitive writing strategies would help learners improve their writing. Besides, in agreement with Panahandeh and Esfandiar (2014), this study showed that metacognitive strategies were positively correlated with writing performance.

However, as opposed to Rahimi and Karbalaei (2016), who did not find any relationship between the use of metacognitive strategies and writing performance of EFL Iranian learners, this study concluded that metacognitive strategies were highly correlated with writing performance. Compatible with the findings of Goudarzi et al. (2015) and Wale and Bogale (2021), the results of this study depicted that metacognitive awareness strategies highly affect achievement scores, and there was a significant correlation between metacognitive awareness strategies and their task performance.

Concerning the relationship between intermediate EFL learners' CTA and their writing performance', it was revealed that intermediate EFL learners' critical thinking abilities were significantly correlated with writing version. As Neimaoui (2019), Renatovna and Renatovna (2021), and Saenab et al. (2021) claim, this study justified that critical thinking ability plays a significant role in EFL learners' writing performances. Furthermore, consistent with the finding of Hall (2017) and Warsah et al. (2021), this study concluded that critical thinking abilities could lead to an improvement in EFL learners' writing performances. Moreover, in agreement with Indah (2017) and Yaralı and Aytar (2021), this study also stated that EFL learners' writing performance was influenced by critical thinking. Furthermore, in line with Al Sharadgah (2014), this study also depicted that those benefiting from a high level of critical thinking abilities would show a more remarkable improvement in their writing. In line with Taghinezhad et al. (2018), this study proved that critical thinking abilities would improve students' writing performance. This study also corroborated Golpour's (2014) finding that critical thinking abilities would play a crucial part in learners' writing performance. In other words, high critical thinkers were better in writing compared to low critical thinkers.

Considering the relationship between intermediate EFL learners' learning strategies and their critical thinking, it was shown that these two variables were significantly correlated. This study is in line with Bagheri (2015) and Zarrinabadi et al. (2021), who reported a significant relationship between CTA and language learning strategies. Besides, this study also confirmed Nikoopour et al. (2011). They surveyed the relationship between CTA and the use of language learning strategies by Iranian language learners. Their findings revealed a significant correlation between cognitive, meta-cognitive, and social strategies with critical thinking. However, as opposed to the results of this study, no relationship was discovered between CTA and memory, compensation, and affective strategies. Besides, congruent with the findings of Ku and Ho (2010), this study found "good critical thinkers" are more active in meta-cognitive activities. Furthermore, this study proved Mahmoodi and Dehghannezhad's (2015) findings that there was a significant and positive correlation between CTA and language learning strategies.

Regarding the mediating role of critical thinking abilities in the relationship between intermediate EFL learners' learning strategies and their writing performances', based on the statistical analysis, it was affirmed that CTA did not play a mediating role in the relationship between intermediate EFL learners' learning strategies and their writing performances. As opposed to the researcher's expectations, and as opposed to the fact that CTA was correlated with both learning strategies and writing performance, this study did not prove that CTA plays a significant role in the relationship between the other two variables. In other words, and surprisingly speaking, CTA does not guarantee the learners' improvement in their writing performance.

CONCLUSION

In the present research, an effort was made to examine the importance of CTA to learners in general and their writing output in particular. As stated earlier, this analysis concluded that there was a significant association between CTA and the writing achievement of EFL intermediate learners. In addition, there was a significant association between learning methods and writing achievements. Furthermore, there was a significant association between the six subgroups of learning strategies and writing results. It was concluded that all the sub-sets of cognitive, metacognitive, memory-related, social, affective, and compensation strategies were highly correlated with writing performance, meaning the use of these strategies would lead to a better performance in the task of writing. In addition, as opposed to what the researcher had envisaged, it was proved that although CTA had correlations with both writing performance and learning strategies, it did not play a mediating role in the relationship between learning strategies and writing performance of intermediate EFL learners.

The present study's findings have shown that more concentration should be placed on critical thinking abilities to enhance students' academic writing performance. Based on the outcomes of the study, it could be concluded that students benefiting from a very high level of CTA did better in their performances than those lacking such a high degree. The findings of this study demonstrate that the students could be more prosperous in their performances if they learn to think critically and if they are aware of the strategies. This attitude can be helpful for all Iranian English students who wish to be competent in perfect performances, especially in their writing performances.

The construction of CTA and learning methods has given rise to looking at teaching, training, and evaluation differently. Taking into account students' needs, desires, and abilities, CTA pedagogy provides resources for authentic learning. The findings of this study depict that the students could be more successful writers if they boost their CTA and their learning strategy use. This can help all Iranian English students who long to be proficient in perfect performances in their writing tasks. In addition, educators can forecast effective language behaviors by defining CTA learner profiles at various stages of growth. Teachers must also understand that different CTA-level learners vary in their learning. Teachers might benefit from the study's findings to realize their students' levels of CTA, and their use of learning strategies would help them develop a sense of competence while being prepared for a performance. CTA is a vital tool that would alleviate writing performance and operate as a practical way to improve the quality of language learning.

In the first place, the results of this study can help teachers know learners' plans in learning writing and assist their students in being responsive to use learning plans in their learning steps and creating a good learning context for using learning plans. Thus, students can become self-sufficient and accept responsibility for their learning. Secondly, curriculum developers may take advantage of the findings to include learning strategies training into the curriculum. As a result, students can use strategies in their learning process more efficiently. The current study can also assist in solving the problems of EFL teachers and learners in enhancing the level of cognitive and meta-cognitive abilities. The results may apprise educators that assisting learners in increasing their level of analysis and monitoring in learning is vital in learning.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.