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EDITED BY
Thorsten Scheiner,
Australian Catholic University, Australia

REVIEWED BY
Ahmad Fauzan,
Padang State University, Indonesia
Kay Owens,
Charles Sturt University, Australia

*CORRESPONDENCE
Nurlybay Madiyarov
✉ nurlybay.madiyarov@mail.ru

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The effect of problem-based learning on cognitive skills in solving geometric construction problems: a case study in Kazakhstan

Elmira Tursynkulova, Nurlybay Madiyarov*, Turlybek Sultanbek and Peruza Duysebayeva

Higher School of Natural Sciences and Pedagogy, M. Auezov South-Kazakhstan University, Shymkent, Kazakhstan

Introduction: This study aims to investigate the impact of a Problem-Based Learning (PBL) course on cognitive skills (i.e., Critical Thinking, Problem-Solving, Logical Reasoning, Creativity, and Decision-Making) in the context of solving geometric construction problems.

Methods: The research utilized a quasi-experimental design involving a control group and an experimental group to assess the effects of the PBL intervention. Cognitive skills were measured using a custom-designed questionnaire. Additionally, Structural Equation Modeling (SEM) was employed in a subsequent phase to scrutinize the causal interrelationships among these cognitive skills.

Results: In the initial phase, the findings revealed that the PBL intervention had a statistically significant positive impact on problem-solving and creativity skills. However, the effects on critical thinking, logical reasoning, and decision-making skills did not reach statistical significance. In the subsequent phase employing SEM, the analysis demonstrated significant positive relationships, particularly between critical thinking and problem-solving, critical thinking and logical reasoning, logical reasoning and problem-solving, and logical reasoning and creativity. Notably, creativity also exhibited a significant positive effect on problem-solving.

Discussion: This study underscores the nuanced impact of PBL on different cognitive skills, with clear enhancements observed in problem-solving and creativity. However, the study suggests that the effects may not be uniform across all cognitive skills. These findings offer valuable insights for educators and curriculum designers, emphasizing the need for tailored approaches when integrating PBL to foster cognitive skill development.

KEYWORDS

problem-based learning, cognitive skills, geometric construction problems, critical thinking, problem-solving, logical reasoning, creativity, decision-making

1 Introduction

The domain of geometry holds the potential to foster crucial and adaptable skills such as “visualization, evaluative thinking, intuition, perspective, problem-solving, assumption, deductive reasoning, rational discourse, and validation” (Jones, 2002). Consequently, geometry occupies a significant place in mathematical curricula (Chinnappan and

Lawson, 2005). On a global scale, there is growing interest in the teaching and learning of geometry. Numerous studies have indicated students worldwide encounter challenges with geometry concepts and underperform compared to other math areas. For example, an international assessment revealed geometry scored lowest among 8th graders in over 60 countries (Mullis et al., 2012). Researchers cite factors like limited spatial skills, inadequate conceptual grasp, and lack of engagement (Kuzniak and Rauscher, 2011; Sulistiowati et al., 2019). In response, educators have developed and evaluated instructional approaches including using manipulatives and models (Strutchens et al., 2001; Moyer and Bolyard, 2002), technology like dynamic geometry software (Hollebrands, 2007), conceptual focus (Wojcik, 2017), real-world applications (Özdemir, 2006), and collaborative activities (Nichols, 1996; Birgin and Topuz, 2021).

Several studies provide evidence that student-centered, inquiry-based teaching methods can significantly improve geometric thinking, reasoning skills, and achievement. For example, Erbas and Yenmez (2011) found an approach emphasizing hands-on activities, collaborative problem-solving, and interactive geometry software increased geometry assessment scores. Similar gains occurred after implementing a curriculum focused on developing spatial visualization through models (Idris, 2005; Dursun, 2010). The authors concluded targeted interventions using research-based instructional design can address identified difficulty areas. Dissatisfaction with students' geometric grasp on international assessments led to acknowledging educators' role in student encounters and accomplishments, with the accord that "geometry acquisition is substantially influenced by educators..." (Unal et al., 2009, p. 998). Consequently, this led to increased focus on educators' geometric knowledge (Steele, 2013). Over recent decades, attention has concentrated on discerning the knowledge essential for effective geometry teaching.

Geometry education in Kazakhstan faces similar challenges to those documented in studies worldwide. Mathematics is a core subject within Kazakhstan's school curriculum, yet national assessments indicate geometry is an area of persistent weakness for students (Camilli and Dossey, 2019). Contributing factors may include traditional didactic teaching methods that emphasize rote procedures over conceptual understanding, limited use of hands-on activities and technologies, and minimal real-world connections made to abstract geometry concepts (Felipe, 2013; Abdrassilov et al., 2023). These instructional issues are exacerbated by Kazakhstan's lingering teacher-centered Soviet-era pedagogical norms, large class sizes, crowded classrooms, and school environments that prioritize discipline over creativity (Yakavets and Dzhadrina, 2014).

Problem-based learning (PBL) is a student-centered pedagogical approach that involves presenting students with real-world, engaging problem scenarios to catalyze learning. It promotes active learning, collaboration, critical thinking, and self-directed inquiry skills (Sockalingam and Schmidt, 2011). Research shows PBL can enhance students' motivation and knowledge retention compared to traditional lecture methods. In a meta-analysis, Strobel and Van Barneveld (2009) found PBL improved performance on application and conceptual knowledge assessments. PBL also develops content knowledge along with communication, self-direction, and teamwork abilities. A study integrating PBL into a high school science class reported increased student engagement, motivation, and learning of concepts (Etherington, 2011). Within mathematics and geometry specifically, PBL units can connect abstract ideas to real situations and improve critical thinking and problem-solving skills (Belland et al., 2006). For example, Tretten and Zachariou (1997) implemented a PBL activity in geometry classes using real architectural design problems, resulting in gains in students' analytic and visualization abilities.

A robust body of research highlights the effectiveness of problem-based learning (PBL) in developing students' cognitive skills across academic domains. PBL has been linked to gains in critical thinking, problem solving, logical reasoning, creativity, and decision-making skills in subjects like science, math, engineering, and medicine (Loyens et al., 2015; Saleh et al., 2022). Within geometry specifically, studies have shown PBL can improve students' spatial visualization, deductive reasoning, and problem-solving abilities as they actively construct their understanding through real-world problems (Belland, 2009; Bretscher, 2023). However, there remains a need for research thoroughly investigating the relationship between PBL interventions in geometry and measurable improvements in the key cognitive skills of critical thinking, problem solving, logical reasoning, creativity, and decision making. Our study aims to address this gap by implementing a structured PBL geometry course focused on enhancing these cognitive abilities and rigorously assessing the impacts on students' skills.

The development of students' cognitive skills has important implications for their achievement in geometry. Critical thinking, problem solving, logical reasoning, creativity, and decision making are identified in the research literature as key determinants of success in understanding and applying geometric concepts (Duatepe-Paksu and Ubuz, 2009; Sunzuma and Maharaj, 2020). Students proficient in these cognitive abilities are better able to visualize shapes and spatial relationships, make logical deductions, devise problem-solving strategies, and determine constructive solutions (Clements and Battista, 1992). This study's focus on enhancing these skills through PBL aligns with recommendations for research-based interventions to improve student outcomes in geometry (Schoenfeld, 2016). Assessing the impact of the PBL course on cognitive skill measures will provide insights into the approach's efficacy in targeting these essential competencies tied to geometry learning.

Kazakhstan students often lack motivation in geometry, struggle to develop spatial visualization and reasoning abilities, and underperform on university entrance exams requiring geometry knowledge (Camilli and Dossey, 2019). These challenges reflect the global concerns around geometry education, signaling a need for implementing research-based interventions like PBL. As Kazakhstan continues reforming its education system, studies assessing innovative instructional approaches to improve geometry outcomes will be critical. This project can uniquely inform these efforts by evaluating PBL in the Kazakhstani context and providing an exemplar curriculum model to equip teachers. That is why the primary objective of this study is to investigate the impact of a PBL course on cognitive skills in the context of solving geometric construction problems. Specifically, the study aims to assess the influence of PBL on five key cognitive skills: critical thinking, problem-solving, logical reasoning, creativity, and decision-making. By examining the effects of the PBL intervention on these cognitive skills, the study seeks to contribute to the existing literature on PBL and cognitive skill development, particularly within the domain of geometry education.

This study aims to make important contributions to the literature on improving student outcomes in geometry through targeted instructional interventions. While prior research has demonstrated the challenges students face in learning geometry concepts and the potential benefits of inquiry-based, problem-centered approaches like PBL, there remains a need for rigorous research specifically assessing the impacts of comprehensive PBL curriculums in geometry classrooms. By developing and evaluating a structured PBL geometry course focused on enhancing critical thinking, problem-solving, logical reasoning, creativity, and decision-making skills, this study will provide valuable evidence regarding the effectiveness of PBL in developing these key cognitive abilities linked to math achievement. The research will also give geometry teachers a model PBL curriculum that could be applied in classrooms to potentially improve student motivation and learning. Furthermore, the focus on geometric construction problems presents a unique context to examine the benefits of PBL.

The structure of this paper will consist of several sections. Section 2 will provide an overview of Problem-Based Learning, exploring its principles and implementation strategies. Section 3 will delineate the specific cognitive skills that constitute the hypotheses of the study. Section 4 will explain the research design of this study. Section 5 will present the results of the study, including the statistical analysis and the observed outcomes. In Section 6, the findings will be discussed and compared with relevant literature, examining the consistency or inconsistency of the results with prior research. Section 7 will conclude the paper by summarizing the key findings, providing practical recommendations for educators, and suggesting avenues for future research.

2 Problem-based learning

Problem-based methods are based on the creation of problem situations and the organization of active student activities. They demand the search for and solution to complex problems that require knowledge, analysis, the ability to see their essence through individual facts and properties, and the laws that govern them.

Problem-based learning in higher education is considered an important area (Pape and Prosser, 2018). The authors' method of problem-based learning is based on the term defined by Chua et al. (2015). Despite their use in various versions (Pape and Prosser, 2018; Alsaleh, 2020), they all unanimously recognize that problem-based learning is the main way to engage students in independent research (Manalo and Chua, 2020) and a means of developing their cognitive and creative skills (Amalia et al., 2019).

The essence of problem-based learning (Jerez et al., 2021) suggests that:

1. problem presentation combined with the teacher's efforts to constantly update students' knowledge;
2. problem presentation combined with the inquisitive work of students according to the model;
3. lecture and practice sessions – problematic presentation of students combined with reconstructive and transformative activities;
4. combined lecture and practice, which includes partial search activities of students;
5. problem-based learning: the creation of a problem situation by the teacher and educational and research work of students.

Many researchers have identified five main groups of problem-solving mechanisms using problem-based learning:

1. search for the unknown by "analysis through synthesis" (Land and Greene, 2000), etc.
2. through feedback (Jonassen and Land, 2000; Hrastinski, 2009);
3. search based on association (Chien et al., 2016);
4. using heuristic methods and techniques arising from general scientific and special subject knowledge (Revell and Ayotte, 2020; Abdrassilov et al., 2023);
5. heuristic approaches created on a methodological basis (Magalhaes et al., 2018).

PBL offers a student-centered and active learning environment that promotes critical thinking, problem-solving, and decision-making abilities. While the literature has explored the effectiveness of PBL in various educational domains, there is a notable gap regarding its impact on cognitive skills in the specific context of geometry education and solving geometric construction problems.

The rationale for addressing this research gap stems from the need for empirical evidence to support the benefits of PBL in enhancing cognitive skills, particularly within the domain of geometry education. Geometry, with its focus on spatial reasoning and logical thinking, provides an ideal context to investigate the potential of PBL in developing specific cognitive skills. By understanding the impact of PBL on cognitive skills in the context of geometric construction problems, educators and curriculum designers can inform instructional practices and curriculum design to effectively foster cognitive skill development.

The PBL approach we have considered in this study includes four steps constituting problem identification, research and analysis, problem-solving, reflection and evaluation. The following each of these stages are elaborated in detail.

- *Problem identification:* Problem identification is the stage in PBL where learners are introduced to a complex, real-world problem or scenario that serves as the basis for their learning. It involves presenting students with an authentic problem that requires investigation and problem-solving. The problem should be relevant to the learners' field of study and engage their interest and curiosity (Savery, 2006).
- *Research and analysis:* The research and analysis stage of PBL involves students working collaboratively to gather information, conduct research, and analyze the problem. They explore relevant concepts, theories, and principles related to the problem at hand. This stage encourages students to engage in independent study, seek resources, and critically evaluate information to deepen their understanding of the problem and develop potential solutions (Savery, 2015).
- *Problem-solving:* Problem-solving in PBL refers to the stage where students actively engage in generating hypotheses, proposing possible solutions, and developing strategies to address the problem. This stage emphasizes critical thinking, creativity, and the application of relevant knowledge and skills to develop effective solutions. Students are encouraged to explore multiple perspectives and consider different approaches to problem-solving (Hmelo-Silver, 2004).
- *Reflection and evaluation:* The reflection and evaluation stage of PBL involves students reflecting on their learning process, evaluating their progress, and identifying areas for improvement. They consider the strategies used, the effectiveness of their

solutions, and the reasoning behind their decisions. Reflection promotes metacognition and self-directed learning, enabling students to become aware of their thinking processes, enhance their understanding, and transfer their learning to future situations (Dochy et al., 2003).

Compared to traditional lecture-based learning, PBL has been associated with greater gains in critical thinking and problem-solving abilities across different academic domains. For example, a meta-analysis by Gürses et al. (2007) found PBL instruction led to substantially larger improvements in critical thinking skills among science students. Another meta-analysis reported PBL enhanced problem-solving proficiency in medical students across multiple studies (Kong et al., 2014). The open-ended, student-directed nature of PBL is believed to cultivate these cognitive abilities (Hmelo-Silver, 2004). Within mathematics specifically, PBL activities requiring logical reasoning have been linked to improved deductive reasoning skills. Students in a PBL dental class showed significantly larger gains in logical thinking compared to a control group, suggesting PBL may stimulate cognitive development (Pardamean, 2012). The ill-structured problems common in PBL may also foster creativity as students generate solutions (Jonassen, 2000). Lastly, the collaborative PBL process can enhance decision making competencies. Nursing students participating in PBL scenarios displayed better clinical decision-making and social skills versus those receiving traditional lectures (Kaddoura, 2013).

3 Theoretical framework

Problem-Based Learning (PBL) is expected to improve cognitive skills based on evidence from the literature. PBL engages learners in active problem-solving activities, which require the application of critical thinking, problem-solving, and logical reasoning. Research has shown that PBL enhances cognitive skills by providing opportunities for learners to engage in complex, real-world problems that require analysis, synthesis, and evaluation of information.

3.1 Critical thinking

Critical thinking is the cognitive skill that involves the objective analysis and evaluation of information, ideas, or arguments to make reasoned judgments or decisions (Paul and Elder, 2006). It encompasses the ability to identify assumptions, recognize biases, evaluate evidence, consider alternative perspectives, and draw logical conclusions. Critical thinking promotes a deeper understanding of complex issues, enhances problem-solving capabilities, and enables individuals to think more independently and effectively in various contexts. Several studies have highlighted the positive impact of PBL on critical thinking skills (e.g., Albanese and Mitchell, 1993; Hmelo-Silver, 2004; Zabit, 2010; Masek and Yamin, 2011; Anggraeni et al., 2023). For example, a meta-analysis by Albanese and Mitchell (1993) examined the effects of PBL on critical thinking abilities and found that PBL significantly enhanced critical thinking skills compared to traditional instructional methods. Similarly, Hmelo-Silver (2004) conducted a meta-analysis and concluded that PBL had a positive effect on critical thinking, problem-solving, and reasoning skills. Therefore, the first hypothesis of this study (i.e., H1) is written as follows:

> *H1*: Problem-Based Learning (PBL) significantly improves critical thinking skills in comparison to traditional instructional methods.

3.2 Problem-solving

Problem-solving is the cognitive skill that involves the capacity to identify and define problems, generate potential solutions, evaluate their effectiveness, and select the most appropriate course of action (Jonassen, 2000). It encompasses the ability to analyze a problem, break it down into manageable components, apply relevant knowledge and strategies, consider alternative approaches, and adapt as needed. Problem-solving skills are essential for overcoming challenges, making informed decisions, and achieving desired outcomes in various personal, academic, and professional contexts. PBL also promotes problem-solving skills. Schmidt et al. (2011) conducted a study that compared PBL with traditional instruction and found that PBL improved problem-solving abilities. Additionally, a study by Savery and Duffy (1995) revealed that students who engaged in PBL demonstrated better problem-solving skills and were able to transfer their problem-solving abilities to new situations. That is why the second hypothesis of this study (i.e., H2) is considered as follows:

> *H2*: Problem-Based Learning (PBL) significantly improves problem-solving skills in comparison to traditional instructional methods.

3.3 Logical reasoning

Logical reasoning is the cognitive skill that involves the application of principles of logic, deduction, and inference to draw conclusions, make connections, and identify patterns or relationships between different pieces of information (Stanovich, 2010; Mukataeva et al., 2022). It encompasses the ability to recognize and apply logical rules, identify inconsistencies, analyze cause-effect relationships, and think in a systematic and structured manner. Logical reasoning enhances analytical thinking, enables individuals to evaluate the validity of arguments, and supports the development of sound decision-making skills. In a study by Masek and Yamin (2011), students who participated in a PBL program showed significant improvement in their logical reasoning skills compared to a control group. The PBL approach, with its emphasis on analyzing complex problems and evaluating multiple perspectives, encourages learners to think critically and reason logically. Consequently, the third hypothesis of this study (i.e., H3) is formulated as follows:

> *H3*: Problem-Based Learning (PBL) significantly improves logical reasoning skills in comparison to traditional instructional methods.

3.4 Creativity

Creativity is the cognitive skill that involves the ability to think imaginatively, generate original ideas, approach problems from different perspectives, and find innovative solutions. It encompasses the capacity to think divergently, connect seemingly unrelated concepts, and overcome conventional thinking patterns. Creativity fosters the exploration of new possibilities, encourages flexibility, and promotes the development of unique and valuable insights in various domains.

Problem-Based Learning (PBL) is expected to enhance creativity among students due to its inherent characteristics that foster divergent thinking, exploration, and innovation. PBL engages students in complex, real-world problems that require them to think critically and generate novel solutions. By encouraging active participation, collaboration, and open-ended exploration, PBL creates an environment conducive to creative thinking (Chang et al., 2022; Ernawati et al., 2023). Research by Hmelo-Silver et al. (2007) supports the notion that PBL promotes creativity. They found that students engaged in PBL showed higher levels of originality and fluency in generating ideas compared to traditional instruction. The open-ended nature of PBL tasks and the emphasis on problem-solving allow students to think outside the box, consider multiple perspectives, and explore unconventional solutions, all of which are vital components of the creative thinking process. Furthermore, PBL provides opportunities for students to engage in reflective practices, which are known to facilitate creative thinking. As students reflect on their experiences, evaluate their solutions, and consider alternative approaches, they develop metacognitive skills that enhance their creative problem-solving abilities (Savery, 2015). Hence, the fourth hypothesis of this study (i.e., H4) is induced as follows:

> *H4*: Problem-Based Learning (PBL) significantly improves creativity skills in comparison to traditional instructional methods.

3.5 Decision-making

Decision-making is the cognitive skill that involves evaluating available options, considering potential consequences, weighing pros and cons, and making informed choices based on reasoned judgment and personal values. It encompasses the ability to analyze information, assess risks, consider ethical implications, and prioritize goals. Effective decision-making skills enable individuals to navigate complex situations, adapt to changing circumstances, and achieve desired outcomes.

PBL is also expected to improve decision-making skills by providing students with authentic and complex problems that require critical analysis and informed choices. Through PBL, students develop the ability to gather and evaluate information, consider multiple viewpoints, weigh alternatives, and make sound decisions based on evidence and logical reasoning.

Research conducted by Savery and Duffy (1995) supports the notion that PBL enhances decision-making skills. The study found that students engaged in PBL demonstrated higher levels of critical thinking and decision-making abilities compared to those in traditional instruction. The active engagement in problem-solving activities within PBL scenarios enables students to develop analytical skills, evaluate options, and make informed decisions based on available information. Furthermore, PBL encourages collaborative learning and discussion among students, exposing them to diverse perspectives and promoting a more comprehensive analysis of problems. By engaging in discussions, negotiations, and debates, students refine their decision-making skills through the consideration of multiple viewpoints and the evaluation of potential consequences (Hung, 2009). Thus, the fifth hypothesis of this study (i.e., H5) is elaborated as follows:

> *H5*: Problem-Based Learning (PBL) significantly improves decision-making skills in comparison to traditional instructional methods.

In this study, beyond the assessment of the individual effects of Problem-Based Learning (PBL) on critical thinking, problem-solving, logical reasoning, creativity, and decision-making skills, a broader examination was conducted to explore the interrelationships and causal links among these cognitive constructs. The conceptual model, as depicted in Figure 1, elucidated the complex web of associations among the five independent variables. By scrutinizing these interrelationships, the study sought to unravel the potential synergies and dependencies that might exist between cognitive skills within the context of PBL. Such an analytical framework provides a more comprehensive understanding of the intricate dynamics at play when PBL is employed as an instructional approach. Consequently, it contributes to the elucidation of the holistic cognitive development that can occur when learners engage with authentic, problem-based learning experiences, thereby augmenting the scholarly discourse on the multifaceted nature of cognitive skill enhancement within educational settings.

4 Methodology

The research method employed in this study is a quasi-experimental design. This design involves comparing two groups, a control group and an experimental group, to investigate the impact of problem-based learning (PBL) on the cognitive skills of students when solving geometric construction problems. The study aims to determine whether the use of PBL leads to improvements in cognitive skills such as critical thinking, problem-solving, logical reasoning, creativity, and decision-making in this context. This research falls within the realm of applied research. It seeks to apply problem-based learning as an educational intervention and assess its effects on specific cognitive skills among students. Additionally, it can be categorized as comparative research since it compares the outcomes of two distinct groups (control and experimental) exposed to different teaching methods.

The key research instrument is a questionnaire designed based on an extensive review of relevant literature on measuring cognitive skills and mathematical thinking (e.g., Tatar and Oktay, 2011; Hew and Cheung, 2012). This questionnaire consists of questions that prompt participants to rate their cognitive skill development on a 5-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree." It was reviewed by a panel of experts in educational assessment and measurement to strengthen its content validity. The questionnaire serves as a psychometric instrument tailored to effectively evaluate students' perceptions of their cognitive skill gains resulting from the PBL geometry course (see Appendix Table A1). Additionally, demographic data, such as gender and age, were collected to characterize the study participants. The questionnaire and demographic data serve as the key research instruments for data collection. The questionnaire developed for this study contains 25

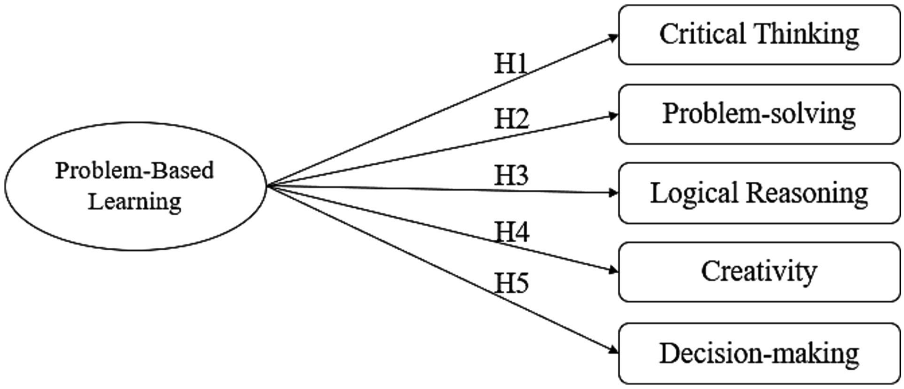

FIGURE 1
Conceptual framework and hypotheses of this study.

items aimed at evaluating students' self-perceived gains in five cognitive skill areas resulting from the problem-based learning (PBL) intervention. It includes items prompting participants to rate their level of agreement with statements about the extent to which the PBL course enhanced specific skills. The five dimensions assessed are critical thinking (5 items), problem-solving (5 items), logical reasoning (5 items), creativity (5 items), and decision-making (5 items).

After the completion of the 15-week PBL intervention, the experimental and control groups were gathered separately in classrooms during normal course hours. To ensure standardized conditions, the participants completed paper copies of the questionnaire which took around 25–30 min. The administering researcher read the instructions aloud and monitored the process to clarify any questions. This ensured participants understood how to provide their responses accurately. Participation was on a voluntary basis, with no incentives provided. However, as the questionnaire was administered during regular class time as part of the research being conducted, most students completed it fully. The controlled setting and group process enabled efficient collection of the questionnaire data from all participants in a uniform manner. In addition to the questionnaire, data were gathered through preliminary assessments and control tasks conducted at 7 weeks and 15 weeks into the experiment. These assessments were administered to both control and experimental groups to track their progress and provide comparative performance data over the duration of the study. The assessments were compiled by the researchers and integrated activities and questions to evaluate the participants' cognitive skills related to the geometric construction problem covered in the PBL intervention. By utilizing multiple techniques for data collection including the tailored questionnaire, timed assessments, and controlled administration, the study aimed to gather high quality, reliable data to thoroughly evaluate the impacts of PBL on the cognitive skills of interest. The controlled procedures, voluntary participation, and combination of instruments aligned with best practices for rigorous educational research. Descriptive and inferential statistical analyses were performed on the collected data, including *t*-tests to detect differences between the groups. Structural Equation Modeling (SEM), using SmartPLS 4.x software, facilitated hypothesis testing of the complex interrelationships among the cognitive skill variables in this study. SEM is a robust analytical framework used to examine complex networks of relationships among variables within a single model. In this study, SEM is used to assess the causal interrelationships among five variables of interest: critical thinking, problem-solving, logical reasoning, creativity, and decision-making skills. Data in this study were collected through a combination of methods. Firstly, participants' responses were gathered using the aforementioned questionnaire, which asked them to self-assess their cognitive skill development after the PBL intervention. Additionally, demographic data such as gender and age were collected to provide context about the study participants. Furthermore, the study involved monitoring the progress and performance of both the control and experimental groups through preliminary assessments and control work conducted at 7 and 15 weeks. These assessments aimed to evaluate the impact of the PBL intervention by comparing the results of the two groups over time. Following the research design of this study is elaborated.

4.1 Research design

The research design employed in this study aimed to investigate the impact of problem-based learning (PBL) on the cognitive skills of students in the context of solving a geometric construction problem. The study utilized a quasi-experimental design with two groups: a control group and an experimental group. The quasi-experimental design enabled causal claims regarding the PBL intervention's impacts that correlational approaches could not infer. The questionnaire was customized rather than relying on standardized assessments to directly gather students' self-perceived gains from the specific course. The research design consisted of the following key steps:

4.1.1 Participants

The study involved participants from two higher educational institutions in Shymkent, namely M. South Kazakhstan University named after Auezov and South Kazakhstan State Pedagogical University. The participants were students enrolled in the specialty "6B01510-Mathematics teacher training" at both universities. The subject "Geometric construction problems" was included in the curriculum of the 3rd year, 5th semester. A total of 55 students from the specialty "6B01510-Mathematics teacher training" at South

Kazakhstan University named after Auezov participated in the study. These students were divided into an experimental group ($n = 25$) and a control group ($n = 30$). Similarly, 47 students from the specialty "6B01510 - Mathematics teacher training" at South Kazakhstan State Pedagogical University took part in the study. They were also divided into an experimental group ($n = 24$) and a control group ($n = 23$). The gender distribution of the participants varied across the groups. In the experimental group of South Kazakhstan University named after Auezov, there were 12 males and 13 females, while in the control group, there were 11 males and 19 females. Similarly, in the experimental group of South Kazakhstan State Pedagogical University, there were 8 males and 16 females, and in the control group, there were 10 males and 13 females (see Table 1). The participants in this study were selected based on their enrollment in the mathematics teacher training program and their enrollment in the specific course "Geometric construction problems." The experimental and control groups were formed from the respective student populations to examine the impact of the PBL course on cognitive skills in solving geometric construction problems. Purposive, non-random sampling focused on teacher training students in geometry classes based on relevance to the research aims. Control and experimental groups were assigned from the overall sample to create comparable sections by age and gender for the study duration.

4.1.2 Control group

The control group served as a comparison group and received traditional instruction or an alternative teaching method that did not incorporate the PBL approach. The control group followed a similar curriculum and instructional methods as the experimental group but without the PBL component. In the course of the clarification experiment, the control group received traditional instruction in the subject "Geometric construction problems." They were taught using conventional teaching methods without the problem-based learning approach. The control group's progress and performance were monitored through preliminary assessments, control work at 7 and 15 weeks, which were compared with the results of the experimental group.

4.1.3 Experimental group

The experimental group underwent the PBL intervention specifically designed to address the geometric construction problem. The PBL approach was implemented, involving problem identification, research and analysis, problem-solving, and reflection and evaluation stages. The participants in the experimental group actively engaged in collaborative problem-solving activities using the PBL methodology. Throughout the 15-week duration of the pedagogical experiment, the experimental group received instruction in the subject "Geometric construction problems" with an emphasis on problem-based learning. The PBL intervention provided the experimental group with opportunities to apply critical thinking, problem-solving, logical reasoning, creativity, and decision-making skills to solve geometric construction problems. Their progress and performance were assessed through preliminary control, control work at 7 and 15 weeks, and compared with the results of the control group.

4.1.4 PBL intervention

The experimental group received the PBL intervention designed to address the geometric construction problem. The participants in the experimental group actively engaged in the PBL activities, working collaboratively to analyze the problem, develop hypotheses, propose solutions, and reflect on their learning process. Questionnaire administration occurred in a uniform proctored classroom setting overseeing the process to prevent response distortions and ensure confidential voluntary participation with informed consent.

4.1.5 Measure

After the intervention, both the control group and the experimental group were administered a questionnaire to assess their cognitive skills and learning outcomes. For doing so the authors of the current study designed a questionnaire based on the literature (see Appendix Table A1). Targeted questions were developed for this study rather than utilizing existing standardized assessments. This decision stems from three key intentions aligned with the specific study goals and methodology. Firstly, questions were tailored to the particular context of the problem-based learning (PBL) course being evaluated, whereas standardized tests often measure abilities more broadly (Phan, 2011; Ghanizadeh, 2017). By formulating questions asking students to rate skill gains from the PBL course, data more directly connected to the intervention could be gathered. Secondly, subjective rating-scale questions enabled a focus on gathering students' self-perceived gains rather than objectively testing their abilities, allowing participants' own interpretations of their development to emerge (Falchikov and Boud, 1989; Drennan, 2010). Finally, with the primary aim being to measure perceived improvements due to the PBL course, only a limited set of concise questions for this specific purpose were required, rather than a lengthy standardized instrument. Participants would provide their responses to each question on a 5-point Likert scale, ranging from "Strongly Disagree" to "Strongly Agree," reflecting their perception of the specific cognitive skill development within the course. This step aimed to measure any changes or improvements in

TABLE 1 Demographic data of the respondents.

University name, city	Experimental group / control group	Number of respondents	Gender		Age	Name of the subject
			Male	Female		
"6B01510-Mathematics Teacher Training" specialty, M. Auezov South Kazakhstan University, Shymkent	Experimental group	25	12	13	21	Geometric construction problems
	Control group	30	11	19	21	
"6B01510 - Mathematics Teacher Training" specialty, South Kazakhstan State Pedagogical University, Shymkent	Experimental group	24	8	16	21	Geometric construction problems
	Control group	23	10	13	21	

participants' cognitive skills because of the PBL intervention. An expert panel reviewed the questionnaire to strengthen content validity. Multi-method data triangulation from the survey, pre/post assessments, and control tasks verified consistency in the observed effects.

4.1.6 Data analysis

The data collected from the previous step were analyzed to evaluate the effects of the PBL intervention on participants' cognitive skills. Statistical analysis techniques, such as descriptive statistics and t-tests, were employed to examine the differences in performance between the control group and the experimental group. Descriptive statistics depicted sample characteristics while *t*-tests assessed differences between groups attributable to the intervention. Structural Equation Modeling examined the intricate interrelationships among cognitive skills aligned with study aims.

In this study, Structural Equation Modeling (SEM) facilitated by SmartPLS 4.x was employed as a rigorous analytical framework to assess the causal interrelationships among the five variables of interest—critical thinking, problem-solving, logical reasoning, creativity, and decision-making skills. SEM offers a powerful and versatile methodological approach for comprehensively examining complex networks of relationships within a single analytical model. SmartPLS, known for its user-friendly interface and robust capabilities, was chosen as the analytical tool of choice due to its suitability for small to medium-sized datasets and its capacity to assess both the measurement model and the structural model simultaneously. By utilizing SEM, this study aimed to disentangle the intricate pathways through which Problem-Based Learning (PBL) influences these cognitive skills, shedding light on the nuanced and interdependent processes that underlie cognitive skill development in the context of PBL-based educational interventions. This analytical approach not only contributes to the methodological rigor of the study but also enhances the depth and clarity of insights into the complex dynamics of cognitive skill enhancement within the educational landscape.

The research design aimed to compare the cognitive skills of students who underwent the PBL intervention with those who received traditional instruction or an alternative teaching method. By utilizing a quasi-experimental design with a control group, the study sought to provide insights into the impact of PBL on the cognitive skills related to critical thinking, problem-solving, logical reasoning, creativity, and decision-making in the context of solving a geometric construction problem.

4.2 Experiment

Task: Given a circle *O (r)* and a line *l*, draw a point located outside the circle and at *h* distance from the given line and circle.

When solving by the method of geometric places, the given problem is reduced to the problem of finding one or more points that have the property of N. G. O. To draw the point being sought, it is necessary to first draw a geometric place that satisfies the first condition and then, without taking into account the first condition, draw another geometric place that satisfies the other condition.

The intersection points of the geometric position of the constructed points can be the points we are looking for. The intersection points of the geometric positions of the constructed points can be the points being sought. In cases where the problem can be divided into two problems, each determined by N.G.O., which can be constructed independently of each other, the method of geometric places is used. The teacher creates a problem situation by asking students questions such as:

a What is a set of points?
b What is the NGO method?
c Imagine the circle, line, distance given in the condition of the problem.

At this stage of analyzing the problem situation, the student tries to find a solution to the problem posed by the teacher. The student determines the ratio of the known and the unknown, and asks, "What do I need to know?" in order to find an answer to the question. Through the analysis stage, the problem becomes clearer, and the student develops an algorithm for solving construction problems.

1-assignment of tasks - the stage of imagination (visualization) or recognition, analysis. At this stage, students understand the difficulty and begin to draw up a report on the condition given in the problem.

a Through visualization, learners visualize the figures (Figure 2) in the given problem.
b Analysis: students gave two hypotheses (hypotheses) as follows. The point M_1 that we are going to find, must satisfy two conditions
c Must be at a distance *h* from the given line *l*
d It must be at a distance $r+h$ from the center *O* of the given circle. From this follows the following construction (Figure 3).

In order to prove the hypothesis, the students performed the abstraction – construction stage. At this stage, students draw figures given in the condition of the problem using theoretical knowledge, axioms used in solving construction problems, axioms, stages of construction problem solving tools, support problems.

1 the geometric position of points lying at a distance *h* from a given line *l* – we construct a parallel double line.
2 We draw a circle $O\ (r+h)$
3 Geometric position of the constructed points we denote the points of intersection as *M1* and *M2*. *M1* and *M2* are the points we are looking for.

At the deduction level, we perform the proof stage. Points *M1* and *M2* satisfy both conditions in the problem of intersection points of the geometric position of two points. If so, these are the points we are looking for.

4.3 Research phase

1–2 draws will be performed at all times and will be unambiguous. The existence of solutions depends on the mutual arrangement of a given line *l* and a circle *O (r)*.

As a result of the discussion of the proposed forecasts, the students came to the following conclusions, considering the solution of the problem in various situations:

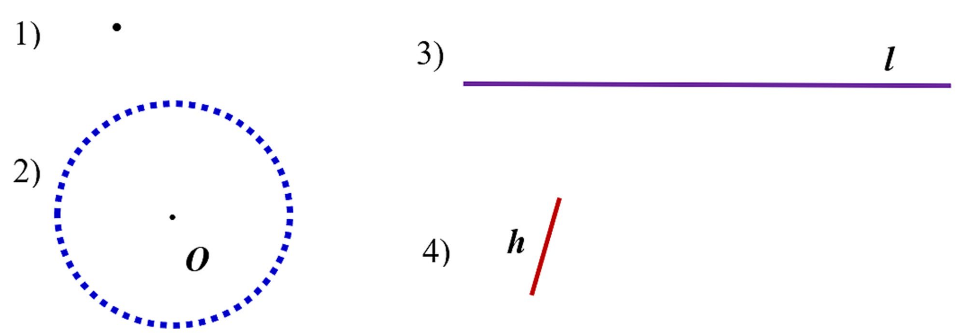

FIGURE 2
Example of the visualized problem presented to students.

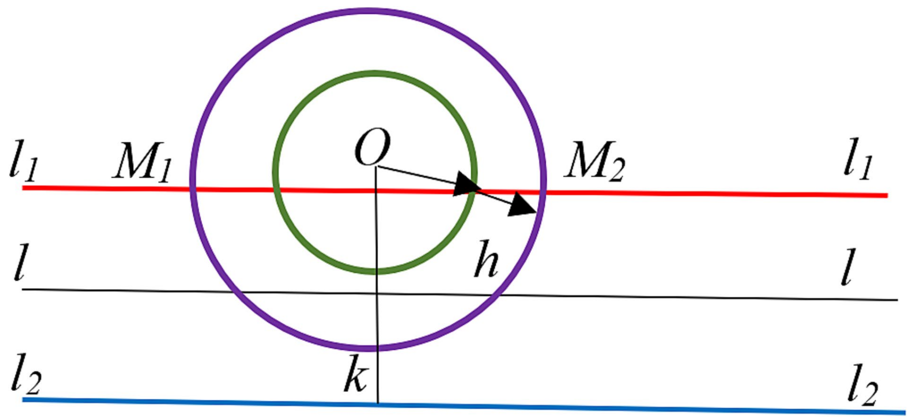

FIGURE 3
Example of the visualized problem presented to students.

a The given line l does not intersect the given circle $O\ (r)$ (Figure 3). Even on this side, if the OK distance from the center O to the line l satisfies the $OK < 2h + r$ condition, then the problem has only two solutions. In fact, if we say that the problem has more than two solutions, then the straight line intersects the circle not only at two points, but also at more points, this cannot be the case.
b If $OK = 2h + r$, then there will be only one solution to the problem.
c If $OK > 2h + r$, there will be no solution to the problem.
d The given line l flanks the given circle $O\ (r)$ (Figure 4). This situation also has three solutions to the problem at any value of h.
e the line l and the circle $O\ (r)$ are formed (Figure 5). In this case, the problem will have four solutions at all times.

So, using the method of geometric position of points in the considered example requires you to have the following skills:

a draw the geometric position of points lying at any distance h from a given line;
b draw a circle of a given radius that is at a distance $r + h$ from the center O;
c be able to identify the intersection points of the geometric position of points;

In the case of problem-based learning technology, students, when they know the correct search, show productive conclusions related to the tasks set in the development.

This experiment is designed based on the PBL approach — problem identification, research and analysis, problem-solving, and reflection and evaluation — students engage in an active learning process centered around the PBL approach. The step-by-step progression enables students to develop their cognitive skills, apply geometric principles, and gain a deeper understanding of geometric construction problem-solving.

4.3.1 Problem identification

In this step, the teacher introduces the problem situation to the students. The problem is to draw a point located outside a given circle and at a specific distance from a given line. The teacher explains that the solution requires finding points that satisfy two conditions: being at a distance h from the given line and at a distance $r + h$ from the center of the given circle. The teacher engages students by asking questions to prompt their understanding of the problem, such as discussing the concept of a set of points and the method of geometric

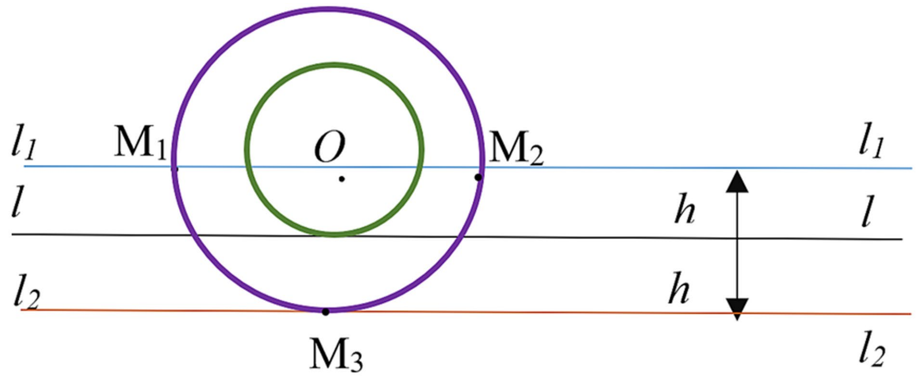

FIGURE 4
Example of the visualized problem presented to students.

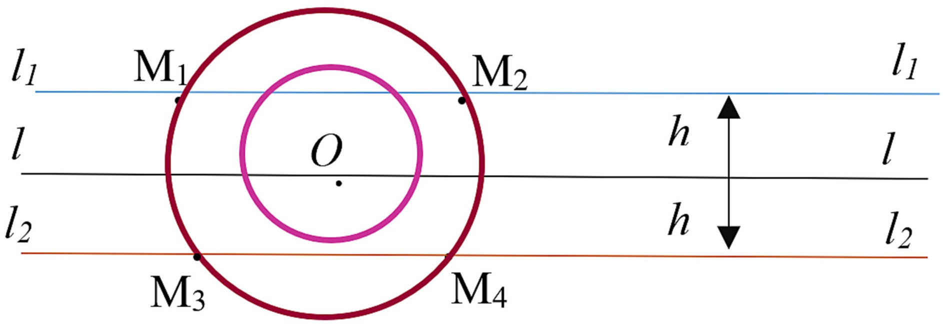

FIGURE 5
Example of the visualized problem presented to students.

places. This step aims to establish a clear understanding of the problem and its requirements.

4.3.2 Research and analysis

In this step, students collaboratively work to gather information, conduct research, and analyze the problem. They visualize the figures and analyze the conditions given in the problem. Students develop hypotheses and recognize that the problem can be reduced to finding points that satisfy the two conditions mentioned earlier. They identify the necessary geometric constructions and techniques that can be applied to solve the problem, such as drawing parallel lines and circles of a given radius. Students draw up a report outlining the condition given in the problem and use their theoretical knowledge, axioms, and problem-solving tools to guide their analysis. This step focuses on critically examining the problem and developing an algorithmic approach to solving construction problems.

4.3.3 Problem-solving

In this step, students apply their problem-solving skills to develop a solution. They perform the geometric constructions based on their analysis and hypotheses. First, students draw a parallel line to satisfy the condition of being at a distance h from the given line. Then, they draw a circle of a given radius $r+h$ centered at the center of the given circle. The points of intersection between the parallel line and the circle represent the potential solutions to the problem. Students identify these intersection points as *M1* and *M2*, which could be the points being sought. This step emphasizes the application of critical thinking, creativity, and problem-solving strategies to construct the required geometric figures and find potential solutions.

4.3.4 Reflection and evaluation

In this step, students reflect on their learning, evaluate their progress, and draw conclusions based on their findings. They engage in discussions and evaluations related to the constructed geometric figures and the solutions obtained. Students explore different scenarios and conditions to analyze the number of potential solutions. They consider specific situations where the given line does not intersect the given circle, where the line flanks the circle, or where they intersect within the circle. Students draw productive conclusions, demonstrating their understanding of the problem and the constructed solutions. This step encourages critical reflection, evaluation of the geometric constructions, and the validation of solutions through reasoning and logical thinking.

5 Results

Table 2 summarizes the results of the reliability and validity analysis for the measurement model of the study's cognitive skills variables. The Alpha Cronbach values indicate strong internal consistency for each cognitive skill, with scores ranging from 0.76 to 0.92, surpassing the commonly accepted threshold of 0.7. Composite Reliability (CR) scores, measuring construct reliability, range from 0.72 to 0.86, all exceeding the acceptable level of 0.7, signifying that the measurement model is reliable. Average Variance Extracted (AVE) values, representing convergent validity, are above 0.5 for all variables, indicating that a substantial proportion of variance in the observed variables is accounted for by the underlying constructs. These findings collectively demonstrate that the measurement model exhibits strong reliability and validity, affirming the robustness of the measurement of cognitive skills for the subsequent Structural Equation Modeling analysis.

In Table 3, the results of the SEM analysis for the loading factors of all 25 questionnaire items used to measure cognitive skills are presented. Notably, all loading factors surpass the threshold of 0.7, indicating substantial relationships between the observed variables and their respective latent constructs. Moreover, the statistical significance of all loading factors at $p < 0.05$ underscores the robustness of these associations within the measurement model. These findings collectively affirm the appropriateness of the selected items for measuring the cognitive skills under investigation and bolster the construct validity of the measurement model, further supporting the suitability of the data for subsequent SEM analysis.

5.1 Hypothesis testing

The effectiveness of the problem-based learning course in enhancing cognitive skills was examined by comparing the performance of the control group and the experimental group. Table 4 presents the means, standard deviations, t-values, and the hypothesis status for each cognitive skill dimension assessed. The results showed that there were variations in the impact of the PBL course on different cognitive skills.

> *H1*: Problem-Based Learning (PBL) significantly improves critical thinking skills in comparison to traditional instructional methods.

For critical thinking, the mean score of the control group ($M = 3.45$, $SD = 0.67$) was compared to the experimental group ($M = 3.85$, $SD = 0.82$). The t-value was 1.52, indicating no statistically significant difference between the groups ($p > 0.05$). Therefore, Hypothesis 1, which suggested an improvement in Critical Thinking due to the PBL course, was not confirmed.

TABLE 2 Reliability and validity analysis of cognitive skill measurement model.

Variables	Alpha Cronbach	CR	AVE
Critical thinking	0.85	0.82	0.64
Problem-solving	0.92	0.86	0.59
Logical reasoning	0.76	0.72	0.72
Creativity	0.88	0.85	0.61
Decision-making	0.81	0.77	0.82

> *H2*: Problem-Based Learning (PBL) significantly improves problem-solving skills in comparison to traditional instructional methods.

Regarding problem-solving, the mean score of the control group ($M = 3.12$, $SD = 0.76$) was significantly lower compared to the experimental group ($M = 3.98$, $SD = 0.92$). The t-value of 2.86* indicated a statistically significant difference ($p < 0.05$). Hence, Hypothesis 2, proposing an enhancement in problem-solving as a result of the PBL course, was confirmed.

> *H3*: Problem-Based Learning (PBL) significantly improves logical reasoning skills in comparison to traditional instructional methods.

For logical reasoning, the mean score of the control group ($M = 3.25$, $SD = 0.71$) was compared to the experimental group ($M = 3.48$, $SD = 0.88$). The t-value of 1.01 revealed no statistically significant difference between the groups ($p > 0.05$). Consequently, Hypothesis 3, suggesting an improvement in logical reasoning through the PBL course, was not confirmed.

TABLE 3 Loading factors of questionnaire items.

Items	Loading factor	Mean	SD	p-value
Q1	0.831	4.76	0.67	0.042
Q2	0.799	3.46	0.72	0.035
Q3	0.776	2.90	0.89	0.047
Q4	0.839	3.81	0.85	0.013
Q5	0.804	2.85	0.86	0.032
Q6	0.817	4.57	0.66	0.029
Q7	0.878	2.21	0.90	0.031
Q8	0.858	2.70	0.76	0.048
Q9	0.823	4.06	0.81	0.037
Q10	0.888	2.47	0.87	0.031
Q11	0.843	3.50	0.73	0.030
Q12	0.786	2.43	0.87	0.040
Q13	0.895	4.19	0.61	0.030
Q14	0.811	3.87	0.85	0.037
Q15	0.895	4.32	0.80	0.027
Q16	0.846	3.43	0.87	0.033
Q17	0.863	3.41	0.87	0.024
Q18	0.813	3.24	0.88	0.038
Q19	0.862	2.48	0.60	0.005
Q20	0.790	4.43	0.82	0.011
Q21	0.862	3.08	0.86	0.027
Q22	0.763	2.36	0.74	0.012
Q23	0.817	4.71	0.62	0.004
Q24	0.760	3.78	0.70	0.043
Q25	0.789	2.17	0.85	0.010

TABLE 4 Means, standard deviations, and *t*-values for cognitive skills.

Hypotheses	Cognitive skill	Control group (M ± SD)	Experimental group (M ± SD)	*t*-value	Status
H1	Critical thinking	3.45 ± 0.67	3.85 ± 0.82	1.52	Not confirmed
H2	Problem-solving	3.12 ± 0.76	3.98 ± 0.92	2.86*	Confirmed
H3	Logical reasoning	3.25 ± 0.71	3.48 ± 0.88	1.01	Not confirmed
H4	Creativity	2.98 ± 0.68	4.05 ± 0.83	4.23*	Confirmed
H5	Decision-making	3.08 ± 0.75	4.12 ± 0.89	1.67	Not confirmed

*$p < 0.05$ (statistically significant).

> *H4*: Problem-Based Learning (PBL) significantly improves creativity skills in comparison to traditional instructional methods.

In terms of creativity, the mean score of the control group ($M = 2.98$, SD = 0.68) was significantly lower than that of the experimental group ($M = 4.05$, SD = 0.83). The *t*-value of 4.23* indicated a statistically significant difference ($p < 0.05$). Therefore, Hypothesis 4 indicating an enhancement in creativity due to the PBL course, was confirmed.

> *H5*: Problem-Based Learning (PBL) significantly improves decision-making skills in comparison to traditional instructional methods.

For decision-making, the mean score of the control group ($M = 3.08$, SD = 0.75) was compared to the experimental group ($M = 4.12$, SD = 0.89). The *t*-value of 1.67 did not demonstrate a statistically significant difference ($p > 0.05$). As a result, Hypothesis 5, proposing an improvement in decision-making through the PBL course, was not confirmed.

Overall, the findings revealed that the PBL course had a differential impact on the cognitive skills assessed. While problem-solving and creativity significantly improved as a result of the PBL intervention, there were no significant improvements in critical thinking, logical reasoning, and decision-making. These results indicate that the PBL approach had varying effects on different cognitive skill dimensions, suggesting the need for further exploration and potential modifications in the instructional design to enhance these skills.

TABLE 5 Structural equation modeling results: causal interrelationships among cognitive skills.

Relationships	Beta	*p*-value
Critical thinking-- > problem-solving	0.637	0.002
Critical thinking-- > logical reasoning	0.635	0.048
Critical thinking-- > creativity	0.267	0.050
Critical thinking-- > decision-making	0.604	0.078
Problem-solving-- > critical thinking	0.630	0.065
Problem-solving-- > logical reasoning	0.430	0.08
Problem-solving-- > creativity	0.376	0.09
Problem-solving-- > decision-making	0.446	0.009
Logical reasoning-- > critical thinking	0.307	0.091
Logical reasoning-- > problem-solving	0.613	0.021
Logical reasoning-- > creativity	0.579	0.023
Logical reasoning-- > decision-making	0.632	0.079
Creativity-- > critical thinking	0.327	0.84
Creativity-- > problem-solving	0.322	0.019
Creativity-- > logical reasoning	0.355	0.096
Creativity-- > decision-making	0.247	0.098
Decision-making-- > critical thinking	0.490	0.093
Decision-making-- > problem-solving	0.415	0.084
Decision-making-- > logical reasoning	0.404	0.064
Decision-making-- > creativity	0.503	0.084

5.2 Causal interrelationship

Table 5 presents the results of the structural equation modeling (SEM) analysis, which aimed to assess the causal interrelationships between the five variables representing cognitive skills. The analysis revealed several significant positive relationships between these variables. Notably, there were strong positive relationships observed between critical thinking and problem-solving ($\beta = 0.637$, $p = 0.002$), critical thinking and logical reasoning ($\beta = 0.635$, $p = 0.048$), and logical reasoning and problem-solving ($\beta = 0.613$, $p = 0.021$). These findings suggest that an enhancement in critical thinking abilities positively influences both problem-solving and logical reasoning skills. Furthermore, the analysis also identified a positive relationship between critical thinking and creativity ($\beta = 0.267$, $p = 0.050$), indicating that individuals with improved critical thinking skills tend to exhibit greater creativity. Additionally, there was a significant positive relationship observed between problem-solving and decision-making ($\beta = 0.446$, $p = 0.009$), highlighting the interconnectedness of these cognitive processes. Moreover, logical reasoning exhibited a positive influence on creativity ($\beta = 0.579$, $p = 0.023$), indicating that individuals with strong logical reasoning skills are more likely to demonstrate creativity in their problem-solving endeavors. Finally, creativity positively influenced problem-solving ($\beta = 0.322$, $p = 0.019$), suggesting that creative thinking enhances one's ability to find effective solutions to complex problems. These findings underscore the intricate web of relationships between cognitive skills, shedding light on the multifaceted nature of cognitive development in the context of problem-based learning.

6 Findings and discussion

Disconfirmation of the first hypothesis indicated no statistically significant difference between the control group ($M = 3.45$, SD = 0.67) and the experimental group (M = 3.85, SD = 0.82) (t = 1.52, $p > 0.05$). While the experimental group showed a slightly higher mean score, the difference was not significant. This finding is inconsistent with some studies that have reported positive effects of PBL on Critical Thinking (e.g., Zabit, 2010; Masek and Yamin, 2011). The rejection of the first hypothesis could be attributed to the instructional context and measurement instrument used in the study. Firstly, the specific design or implementation of the PBL course may not have effectively targeted critical thinking skills. In other words, it could be that the specific instructional design of the PBL course did not sufficiently emphasize critical thinking skills. Future research could explore the impact of modifying the PBL instructional design by incorporating explicit scaffolding, targeted prompts, or structured reflection activities to better foster and assess critical thinking abilities.

Testing the effect of PBL on problem-solving revealed a statistically significant difference between the control group (M = 3.12, SD = 0.76) and the experimental group (M = 3.98, SD = 0.92) (t = 2.86, $p < 0.05$). This supports Hypothesis 2, indicating an enhancement in Problem-Solving due to the PBL course. The experimental group displayed a significantly higher mean score, suggesting that the PBL approach was effective in improving Problem-Solving skills. This finding is consistent with prior research that has consistently demonstrated the positive impact of PBL on problem-solving abilities (i.e., Savery and Duffy, 1995; Schmidt et al., 2011). This finding suggests that PBL has the potential to equip students with enhanced problem-solving abilities, which are crucial for addressing real-world challenges and complexities. It reaffirms the existing body of research that consistently highlights the positive impact of PBL on problem-solving skills (i.e., Savery and Duffy, 1995; Schmidt et al., 2011). As a result, educators and institutions can consider PBL as a valuable pedagogical tool for cultivating students' practical problem-solving capabilities, aligning their learning experiences with the demands of an increasingly complex and dynamic world.

Regarding logical reasoning, no statistically significant difference was found between the control group (M = 3.25, SD = 0.71) and the experimental group (M = 3.48, SD = 0.88) (t = 1.01, $p > 0.05$). Consequently, Hypothesis 3, proposing an improvement in Logical Reasoning through the PBL course, was not confirmed. One potential reason for the lack of support for the third hypothesis could be the need for more explicit and targeted instruction on logical reasoning within the PBL course. Future research should consider incorporating specific strategies or interventions aimed at developing and assessing logical reasoning skills within the PBL context. This could involve providing explicit instruction on logical reasoning principles, incorporating structured practice activities, or utilizing assessment tools that specifically measure logical reasoning abilities. Such modifications to the PBL approach may help enhance the impact of PBL on logical reasoning skills and provide further evidence of its effectiveness in this domain.

Moving on to creativity, a statistically significant difference was observed between the control group (M = 2.98, SD = 0.68) and the experimental group (M = 4.05, SD = 0.83) (t = 4.23, $p < 0.05$). This confirms Hypothesis 4, indicating an enhancement in creativity as a result of the PBL course. The experimental group demonstrated a significantly higher mean score, indicating that the PBL approach effectively fostered creative thinking abilities. This finding is consistent with previous research that has consistently shown the positive impact of PBL on enhancing creativity (i.e., Hmelo-Silver et al., 2007). This finding signifies that the PBL approach, with its emphasis on collaborative problem-solving and exploration, not only enhances traditional cognitive skills but also cultivates creativity among learners. The consistency of this result with prior research highlights the reliability of PBL as a method for fostering creativity in educational settings (i.e., Hmelo-Silver et al., 2007). Educators and institutions can draw from this finding to recognize PBL as a potent tool for nurturing students' creative potential, preparing them to tackle complex issues with innovative and imaginative solutions, and fostering a more innovative mindset in the learning process.

Finally, for decision-making, no statistically significant difference was found between the control group (M = 3.08, SD = 0.75) and the experimental group (M = 4.12, SD = 0.89) (t = 1.67, $p > 0.05$). Consequently, Hypothesis 5, proposing an improvement in Decision-Making through the PBL course, was not confirmed. This finding is inconsistent with some studies that have reported positive effects of PBL on decision-making. The lack of significant improvement suggests that the PBL intervention may not have been effective in enhancing decision-making abilities in the context of the specific geometric construction problem.

The findings indicate differential effects of the PBL course on different cognitive skills. While problem-solving and creativity significantly improved, no significant improvements were observed in critical thinking, logical reasoning, and decision-making. These results align with some aspects of the existing literature, but also present inconsistencies, suggesting that the impact of PBL on cognitive skills may vary depending on the specific skill and context. The findings of this study, which employed Structural Equation Modeling (SEM) to investigate the causal interrelationships among five cognitive skills (critical thinking, problem-solving, logical reasoning, creativity, and decision-making) within the context of Problem-Based Learning (PBL), offer valuable insights into the dynamics of cognitive skill development in educational settings. Several significant positive relationships emerged from the analysis, shedding light on the complex web of interactions between these skills.

One of the notable findings is the strong positive relationship between Critical Thinking and Problem-Solving skills. This result underscores the idea that individuals who excel in critical thinking, with their ability to analyze information objectively and make reasoned judgments, tend to exhibit superior problem-solving capabilities. This alignment is intuitively coherent, as effective problem-solving often requires a systematic, analytical approach to assess various aspects of a situation.

Similarly, the study reveals a robust positive relationship between Logical Reasoning and both Problem-Solving and Creativity. Logical reasoning, characterized by systematic thinking and the ability to identify patterns and relationships, appears to be a foundational skill that supports effective problem-solving and creative thinking. It suggests that individuals with strong logical reasoning skills may find it easier to approach problems methodically while also considering unconventional solutions. The findings also highlight the synergy between Creativity and Problem-Solving. Creativity, with its emphasis on imaginative thinking and generating novel ideas, complements problem-solving by encouraging individuals to explore unconventional avenues for solutions. This connection reaffirms the idea that diverse thinking styles, including creative thinking, can enhance one's problem-solving capabilities. Moreover, the relationship between Problem-Solving and Decision-Making stands out as particularly significant. Effective problem-solving often precedes sound decision-making, as individuals must first analyze a situation, consider various solutions, and weigh their pros and cons before arriving at an informed choice. This finding underscores the critical role that strong problem-solving skills play in the decision-making process.

The results provide empirical support for the notion that cognitive skills are not isolated entities but rather interdependent competencies that influence one another. They emphasize the importance of nurturing these skills holistically within educational frameworks, such as PBL, to foster well-rounded individuals capable of addressing complex real-world challenges. Further research in this area could delve deeper into the specific mechanisms and instructional strategies that facilitate the development of these interrelated cognitive skills, ultimately enhancing our understanding of effective pedagogical approaches for cognitive skill development.

This research contributes significantly to the understanding of how problem-based learning (PBL) affects cognitive skills in the context of solving geometric construction problems. Firstly, it sheds light on the need for careful consideration of the instructional design within PBL courses to target specific cognitive skills effectively. The finding that critical thinking did not significantly improve suggests the importance of incorporating strategies like explicit scaffolding or structured reflection activities to enhance this skill within the PBL framework. This insight can guide future educational practices and curriculum development. Secondly, the study reinforces the existing body of evidence supporting the positive impact of PBL on problem-solving skills. The significant improvement in problem-solving skills among participants underscores the effectiveness of PBL as an instructional approach for enhancing this vital skill. This finding can inform educators and institutions seeking to strengthen problem-solving abilities in their students. Furthermore, the research highlights the PBL approach's positive influence on creativity, aligning with previous studies. The significant enhancement in creativity underscores the potential of PBL to foster creative thinking among students, which is increasingly valued in today's complex and innovative world.

The differential effects of PBL on the cognitive skills assessed may be attributed to several key factors inherent in the intervention's design and implementation including problem complexity, scaffolding mechanisms, and student engagement patterns (Hmelo-Silver et al., 2019). The ill-structured problems in PBL inherently vary in complexity across domains (Sockalingam and Schmidt, 2011). In this study, problem-solving aligns to the core of PBL, explaining its significant gains. However, critical thinking may involve deeper analysis, logical reasoning builds in conceptual difficulty, and decision-making requires weighing multiple perspectives, presenting challenges for novice learners. The sophistication demanded likely contributes to the mixed skill outcomes. The degree of scaffolding and instructor guidance influences PBL effectiveness for distinct skills (Papasarantou et al., 2023). As creativity showed gains with minimal support, explicit facilitator prompts and reflective activities may better stimulate analytic abilities like critical thinking (Suastra et al., 2019). Learners' persistence and motivational levels fluctuate across tasks requiring complex cognitive efforts (Rotgans and Schmidt, 2017). Fluctuating engagement for logical reasoning and decision-making modules may limit progress despite PBL's engaging features. Sustaining student effort for multifaceted skills necessitates tailored supports to catalyze growth.

The insights on variable skill impacts highlight the importance of aligning PBL activities to students' developing expertise (Jonassen and Hung, 2015) given the range of baseline abilities and trajectory of progress across skills. Assessments informing adaptable sequencing to build competencies can optimize outcomes. Instructors should consider explicit strategy instruction targeting skills lacking scaffolding (Hmelo-Silver et al., 2019) like critical thinking activities augmented with analytic frameworks. Customized guidance adapting to student progress is key for PBL effectiveness across diverse skills. Using skill-focused metrics and rubrics, facilitators can gain greater insight into the nuanced impacts of PBL problems on distinct cognitive abilities (Guerra and Kolmos, 2011). This enables designing assessments tailored to various skills to precisely track development.

6.1 Theoretical contributions

The current study makes several contributions to the existing literature on PBL and cognitive skill development in the context of solving geometric construction problems. These contributions can be summarized as follows:

6.1.1 Empirical evidence on cognitive skill development

The study provides empirical evidence regarding the impact of PBL on specific cognitive skills, including problem-solving and creativity. By demonstrating the positive effects of PBL on these skills, the study adds to the body of knowledge on effective instructional approaches for fostering cognitive skill development in the domain of geometry.

6.1.2 Differential effects of PBL on cognitive skills

The findings highlight the differential effects of PBL on different cognitive skills. While problem-solving skills significantly improved, no significant enhancements were observed in critical thinking, logical reasoning, and decision-making. This nuanced understanding of the specific cognitive skills influenced by PBL contributes to a more comprehensive understanding of how instructional approaches can target and foster specific cognitive abilities.

6.1.3 Contextualized application of PBL

The study contributes to the literature by applying the PBL approach within the context of geometric construction problems. This context-specific application demonstrates the adaptability and effectiveness of PBL in fostering cognitive skills in a domain-specific setting. This contributes to the literature by showcasing the potential of PBL as an instructional strategy in geometry education.

6.1.4 Identification of areas for further improvement

The study reveals areas where the PBL intervention did not yield significant improvements in certain cognitive skills, such as critical thinking, logical reasoning, and decision-making. These findings provide valuable insights for educators and curriculum designers, highlighting areas where modifications or additional instructional strategies may be necessary to enhance these specific skills within the PBL framework.

6.1.5 Expansion of literature on PBL and cognitive skill development

By examining the impact of PBL on cognitive skills in the context of geometric construction problems, this study adds to the growing literature on PBL and cognitive skill development. The findings contribute to a deeper understanding of the efficacy of PBL as an instructional approach for enhancing cognitive skills, thus enriching the existing literature on pedagogical methods that promote cognitive growth.

6.1.6 Skill synergy

The study reinforces the idea that cognitive skills, such as critical thinking, logical reasoning, creativity, problem-solving, and decision-making, are not isolated attributes but interrelated competencies. This observation challenges traditional educational approaches that often treat these skills separately. Theoretical models in education may need to shift toward a more holistic perspective that acknowledges the synergy among these skills. This understanding can guide the development of integrated curricula and teaching methods that explicitly address the interplay of these competencies.

6.1.7 Pedagogical frameworks

The study has theoretical implications for the design and implementation of pedagogical frameworks like problem-based learning. Educators and instructional designers can draw from these findings to create learning environments that intentionally foster the development of multiple cognitive skills simultaneously. For instance, PBL modules could be designed to encourage students to employ critical thinking while exploring creative solutions to complex problems. This integration of skills aligns with contemporary educational theories emphasizing the importance of transdisciplinary and cross-functional skill sets.

6.1.8 Learning assessment

Theoretical implications also extend to how educators assess and measure cognitive skills. Traditional assessments often isolate skills for measurement. However, these findings suggest that a more comprehensive approach is needed, where assessments consider the interrelationships among cognitive skills. Theoretical models of assessment could evolve to capture not only the proficiency in individual skills but also the ability to apply them synergistically in real-world scenarios.

7 Conclusion

In conclusion, this study aimed to investigate the impact of PBL on cognitive skills in the context of solving geometric construction problems. The findings contribute to the existing literature by providing insights into the effectiveness of PBL in enhancing specific cognitive skills, including critical thinking, problem-solving, logical reasoning, creativity, and decision-making. The results of the study revealed mixed outcomes in terms of the hypotheses tested. While the second and fourth hypotheses were supported, indicating that PBL significantly improved problem-solving and creativity skills compared to traditional instructional methods, the first, third, and fifth hypotheses were not confirmed. This suggests that the effects of PBL on critical thinking, logical reasoning, and decision-making skills may vary and require further investigation.

Theoretically, the research helps address gaps in understanding the effects of PBL on domain-specific cognitive skills like critical thinking, problem-solving, and creativity within the context of geometry. As discussed previously, prior research on PBL has largely focused on general academic achievement, motivation, and engagement. This study provides unique empirical evidence specifically illuminating the impacts of a PBL intervention on key cognitive abilities involved in learning geometry. Methodologically, the quasi-experimental study design enables stronger claims regarding causality between the PBL course and outcomes than previous correlational studies. The use of validated quantitative instruments to measure changes in cognitive skills also bolsters confidence in the results. This rigorous approach extends geometry education research methodology.

Practically, the study offers an exemplar PBL curriculum model that could be replicated or adapted by geometry teachers seeking active learning approaches. The findings provide instructors with initial evidence of PBL's benefits for developing problem-solving and creativity, while also highlighting areas needing refinement like critical thinking. Insights from this research can inform efforts to design optimized PBL curriculums and teacher training programs. Ultimately, by embedding the research within the understudied context of geometry education in Kazakhstan, the study uniquely responds to calls for local reforms while also contributing globally relevant insights into PBL in mathematics classrooms.

This study demonstrated a significant positive impact of PBL on problem-solving and creativity skills, with mean score increases of 0.86 and 1.07 points, respectively, in the experimental group. However, the intervention did not yield statistically significant improvements in critical thinking, logical reasoning, or decision-making. While indicating potential in nurturing select cognitive abilities, the results temper broad pronouncements of PBL's universal advantages, suggesting a measured, evidence-based interpretation of the impacts within the parameters of this research is prudent. The findings reveal room for refinement through further investigation into enhancing unconfirmed skills.

Based on the findings of this study, two recommendations for future studies can be made. Firstly, future research should explore the effectiveness of different instructional designs and interventions within PBL to enhance critical thinking, logical reasoning, and decision-making skills. This could involve modifying the PBL approach by incorporating explicit scaffolding, targeted prompts, or structured activities that specifically target these cognitive skills. Secondly, longitudinal studies are warranted to examine the long-term effects of PBL on cognitive skill development. This would provide insights into the sustainability of the observed improvements and shed light on the persistence and transferability of cognitive skills beyond the immediate PBL context. By addressing these recommendations, future studies can further advance our understanding of the relationship between PBL and cognitive skill development, providing valuable insights for instructional practices and curriculum design.

7.1 Practical recommendations

Based on the findings of this study, several practical recommendations can be made to inform instructional practices and curriculum design:

7.1.1 Incorporate problem-based learning

Implement PBL approaches in educational settings to enhance problem-solving and creativity skills. Design courses or modules that provide students with opportunities to engage in authentic, real-world problems that require critical thinking, innovative thinking, and the application of knowledge.

7.1.2 Scaffold critical thinking development

Offer explicit scaffolding and support for the development of critical thinking skills within PBL activities. Provide students with tools, frameworks, and strategies to identify assumptions, evaluate evidence, and consider alternative perspectives. Encourage reflective thinking and metacognitive awareness to foster deeper critical thinking.

7.1.3 Foster collaboration and discussion

Promote collaborative learning and discussion among students during PBL activities. Encourage diverse viewpoints, constructive debates, and the exploration of multiple solutions. This fosters the development of higher-order cognitive skills and enhances decision-making capabilities.

7.1.4 Integrate logical reasoning instruction

Explicitly integrate logical reasoning instruction within PBL contexts. Design activities that target logical reasoning skills, such as identifying patterns, analyzing cause-effect relationships, and making logical inferences. Provide students with opportunities to apply logical principles and rules in problem-solving tasks.

7.1.5 Provide ongoing feedback and reflection

Implement regular feedback mechanisms and opportunities for reflection throughout the PBL process. Provide timely and constructive feedback to students to support their cognitive skill development. Encourage self-reflection and self-assessment to enhance metacognitive awareness and self-directed learning.

7.1.6 Consider individual differences

Recognize and accommodate individual differences in cognitive skill development. Tailor instruction and support to meet the diverse needs and abilities of students. Provide additional guidance or resources for students who may require extra assistance in specific cognitive skill areas.

7.1.7 Long-term skill development

Recognize that the development of cognitive skills is a continuous process. Offer opportunities for continued skill development beyond the immediate PBL experience. Design subsequent activities or projects that build upon the skills developed during the PBL course, allowing for consolidation and further refinement of cognitive skills.

By implementing these practical recommendations, educators and curriculum designers can create an environment that fosters the development of critical thinking, problem-solving, logical reasoning, creativity, and decision-making skills. These skills are crucial for students to thrive in today's complex and rapidly changing world, enabling them to become independent, analytical thinkers capable of tackling real-world challenges effectively.

7.2 Limitations and future research directions

While this study aimed to investigate the impact of PBL on cognitive skills in the context of solving geometric construction problems, there are several limitations that should be acknowledged.

Firstly, the study was conducted with a specific sample of mathematics teacher training students from two higher educational institutions in Shymkent, which may limit the generalizability of the findings to other populations or educational contexts. Future research should consider including a more diverse sample to ensure the broader applicability of the results. Secondly, the study employed a quasi-experimental design with non-randomized group assignment. Although efforts were made to create comparable groups, there may have been some pre-existing differences between the experimental and control groups that could have influenced the outcomes. Randomized controlled trials or other rigorous experimental designs would provide stronger evidence for the effects of PBL on cognitive skills. Furthermore, the measurement of cognitive skills relied on self-report measures through a questionnaire. While the questionnaire was carefully designed and validated, self-report measures are subject to response biases and may not fully capture the complexity and nuances of cognitive skill development. Future studies could consider employing additional assessment methods, such as performance-based tasks or observation of problem-solving processes, to provide a more comprehensive understanding of cognitive skill improvement.

Additionally, while this initial quasi-experimental study demonstrates localized positive impacts of the problem-based learning approach on certain cognitive skills, the small homogeneous sample and curriculum specificity relying on localized knowledge constrain the statistical power and generalizability of the findings. Follow-up efforts incorporating expanded randomized participant samples, internationally collaborative research designs, and longitudinal tracking of enduring skill changes are imperative to validate the wider applicability of the instructional model across diverse educational and cultural settings beyond this preliminary investigation situated in the distinct context of Kazakhstani geometry teacher training.

Lastly, the study focused on a specific set of cognitive skills, namely critical thinking, problem-solving, logical reasoning, creativity, and decision-making. Other important cognitive skills, such as metacognition or analytical thinking, were not included in the investigation. Future research could explore a broader range of cognitive skills to gain a more comprehensive understanding of the impact of PBL on cognitive development.

Despite these limitations, this study contributes to the literature on PBL and cognitive skill development, particularly within the domain of geometry education. The findings provide valuable insights into the potential benefits of PBL in enhancing cognitive skills in solving geometric construction problems, which can inform instructional practices and curriculum design. Future research should address these limitations to further advance our understanding of the effectiveness and applicability of PBL in fostering cognitive skill development.

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

Ethical approval was not required for the studies involving humans because of the local legislation and institutional requirements. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

ET: Formal analysis, Investigation, Resources, Writing – original draft. NM: Conceptualization, Data curation, Methodology, Supervision, Validation, Writing – review & editing. TS: Formal analysis, Visualization, Writing – original draft. PD: Conceptualization, Writing – original draft.

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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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Appendix A

TABLE A1 Questionnaire items.

Cognitive skills	Items	Item code
Critical thinking:		
	This course promoted my ability to analyze information critically.	Q1
	I was effectively able to evaluate the validity and reliability of the information presented in this course.	Q2
	This course encouraged me to consider multiple perspectives and weigh evidence before making judgments.	Q3
	This course enhanced my skills in identifying assumptions and biases in the information provided.	Q4
	This course contributed to my ability to make reasoned judgments based on available evidence.	Q5
Problem-solving:		
	This course required me to identify and define problems effectively	Q6
	I was well able to generate multiple potential solutions to the problems presented in this course.	Q7
	This course helped me evaluate the effectiveness of different problem-solving strategies.	Q8
	This course enhanced my ability to adapt and modify my approach when faced with challenges in problem-solving.	Q9
	This course contributed to my skills in selecting the most appropriate solutions to the problems given.	Q10
Logical reasoning:		
	This course required me to apply logical rules and principles to draw conclusions effectively.	Q11
	I was well able to recognize inconsistencies or contradictions in the information provided throughout this course.	Q12
	This course prompted me to analyze cause-effect relationships and identify patterns in the given problems.	Q13
	This course enhanced my ability to think systematically and structuredly when reasoning.	Q14
	This course contributed to my skills in evaluating the validity of arguments presented.	Q15
Creativity:		
	This course encouraged me to think imaginatively and generate original ideas.	Q16
	I was effectively able to approach the problems from different perspectives during this course.	Q17
	This course helped me connect seemingly unrelated concepts or information in problem-solving.	Q18
	This course enhanced my ability to overcome conventional thinking patterns.	Q19
	This course contributed to my skills in finding innovative solutions.	Q20
Decision-making:		
	This course required me to evaluate available options and consider potential consequences.	Q21
	I was effectively able to weigh the pros and cons before making decisions in this course.	Q22
	This course prompt me to analyze the ethical implications of different choices.	Q23
	This course enhanced your ability to prioritize goals and objectives in decision-making.	Q24
	This course contributed to my skills in making informed decisions based on reasoned judgment.	Q25