



# Exploring the Effectiveness of STEAM-Based Courses on Junior High School Students' Scientific Creativity

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The purpose of this study is to explore the effectiveness of a STEAM (Science, Technology, Engineering, Arts, Mathematics) -based curriculum on junior high school students' scientific creativity. The main topic of the STEAM-based curriculum in this study is an ancient mechanical clock that was designed and produced by the authors' team. Further, the main concept of the ancient mechanical clock is about a gear wheel. Hence, this study designed two stages of courses which were gear wheel science courses (2 weeks) and STEAM-based courses (2 weeks). A total of 62 junior high school students from two different courses participated in this study and were divided into a control group and an experimental group. This study adopted a counterbalance design. The control group joined gear wheel science courses first and joined STEAM-based courses second. In contrast, the experimental group joined STEAM-based courses first. Both groups were asked to complete a pre-test, a middle-test, and a post-test by completing the "Scientific Creativity Test (Cronbach's  $\alpha$  0.87)". The results from paired *t*-test analyses showed that control group students did not show significant differences in scientific creativity before and after joining the gear wheel science courses, but they got significantly higher scores after joining STEAM-based courses than before. On the other hand, the experimental group students got higher scores in scientific creativity after joining STEAM-based courses than before, and persisted in getting higher scores after joining the gear wheel courses than before. Furthermore, the results implied that the STEAM-based courses might help students maintain or continue their scientific creativity. Further discussion is provided.

**Keywords:** scientific creativity, science education, creativity, junior high school, steam

## INTRODUCTION

Creativity is a specific human ability that can be used to solve real-life problems in novel and useful ways (Guilford, 1950; Huang et al., 2017; Huang and Wang, 2019). Not only do educators and researchers say that creativity is an important educational purpose for the future (Shi et al., 2017; Suyidno et al., 2019), but also PISA 2021 focused on the issue of creative thinking in schools (Bouchie, 2019). Unfortunately, although a lot of researchers of educators have agreed that scientific creativity is very important for a long time, there are few systematic training courses in formal education (Suyidno et al., 2019). For this reason, this study aims to design a systematic curriculum in school for trying to improve students' creativity.

Many previous studies have investigated the important indices that improve human creativity (Lubart, 1994; Feldhusen and Goh 1995; Thuneberg et al., 2018; Conradt and Bogner, 2019). They discovered that participants with high creativity abilities frequently have a vigorous curiosity and can

connect their knowledge and experiences to produce some new ideas. In other words, interdisciplinary thinking skills will be a key factor in training human creativity. STEAM (science, technology, engineering, art, and mathematics) subjects, according to Conradt and Bogner (2019), are a type of interdisciplinary integration, and they investigate 11–12 years old students' creativity by teaching STEAM courses. Besides, Perignat and Katz-Buonincontro (2019) demonstrated in an integrative literature review that the combination of the arts with STEM subjects to become STEAM (Science, Technology, Engineering, Arts, and Mathematics) education can improve student engagement, creativity, innovation, problem-solving skills, and other cognitive benefits. In addition, Conradt and Bogner (2019) claimed that including the arts in STEM education might assist students by fostering innovative solutions. As a result, creativity is linked to the arts and is employed as one of the advantages or learning objectives of STEAM education. They also found that the students' self-reported aspects of creativity were not affected by using a single STEAM intervention. In contrast, Ozkan and Topsakal (2019) used the STEAM design process program to investigate middle school seventh-grade students' creativity and discovered that the students' verbal and numerical creativity had significantly improved. Did the different findings come from different definitions of creativity or from different curriculum designs?

In the aspect of the definition of creativity, Mayer (1999) has already mentioned that the definition of creativity is many and varied. This means the discussion about creativity will be affected by different points of view. Csikszentmihalyi (1996) also indicated that creativity is domain-specific, and although the cognitive structure of creativity is similar, the nature of domain-specific creativity is very different in the individual domains. For example, scientific creativity is a kind of domain-specific creativity, and humans will perform their scientific creativity by combining their science background knowledge and domain-relevant creativity (Sternberg and Lubart, 1993; Amabile, 1996; Hu and Adey, 2002; Ayas and Sak, 2014; Huang and Wang, 2019). In this coming decade, the industrial revolution 4.0 will push forward the transition of science, engineering, and technological knowledge, and students across the whole world should speed up to improve their science background knowledge. Moreover, the problems of environmental change such as climate change, air pollution, micro-fiber or micro-plastic issues in the ocean, etc., need to be solved by using scientific knowledge and creativity. Therefore, this study concentrates the definition of creativity on scientific creativity in this research.

On the other hand, this study also wants to clarify what is a suitable STEAM-based curriculum design for helping students improve their scientific creativity. Ngo and Phan (2019) mentioned that the multi-disciplinary approach in project-based learning (PBL) strategies is suitable to the concept of STEAM. PBL strategies can successfully assist students to increase their creativity and get positive feedback from students; PBL strategies are also recommended to continue to be researched and applied in schools in the future (Gunawan et al., 2017; Ismuwardani et al., 2018; Lou et al., 2017). In Ngo and

Phan's research, they referred that some previous research mentioned that PBL strategies could help students improve their attitude and skills, but fewer effects for improving students' knowledge. Ngo and Phan hypothesized that this was due to a lack of suitable projects in the early stages of the research. Therefore, further studies are needed.

## Hypotheses

In order to approve that STEAM-based courses are influential on students' scientific creativity, this study designed a two-stage STEAM-based curriculum by using project-based learning strategies. The main topic of STEAM-based curriculum is completing a project—to assemble an ancient mechanical clock and inquiry the reasons of different results from different conditions. The two stages of this curriculum involve “Gear Wheel Science Courses” and “STEAM-based courses”. The details of curriculum design will describe in next section (Method section).

In a previous study, Tran et al. (2021) demonstrated that the STEAM-based curriculum could increase students' scientific creativity. In particular, in the three components of scientific creativity (fluency, flexibility, and originality), the fluency and flexibility components showed a significant improvement; and the effects of the STEAM-based curriculum on various genders are obviously similar. This conclusion, however, is restricted to elementary school students. Furthermore, they are unable to indicate which stage supports the students' scientific creativity more actively. Therefore, this study wishes to broaden the participants and better understand which kind of sequence of course stage design is more effective in improving students' scientific creativity, as well as the influence of STEAM-based courses on students' scientific creativity.

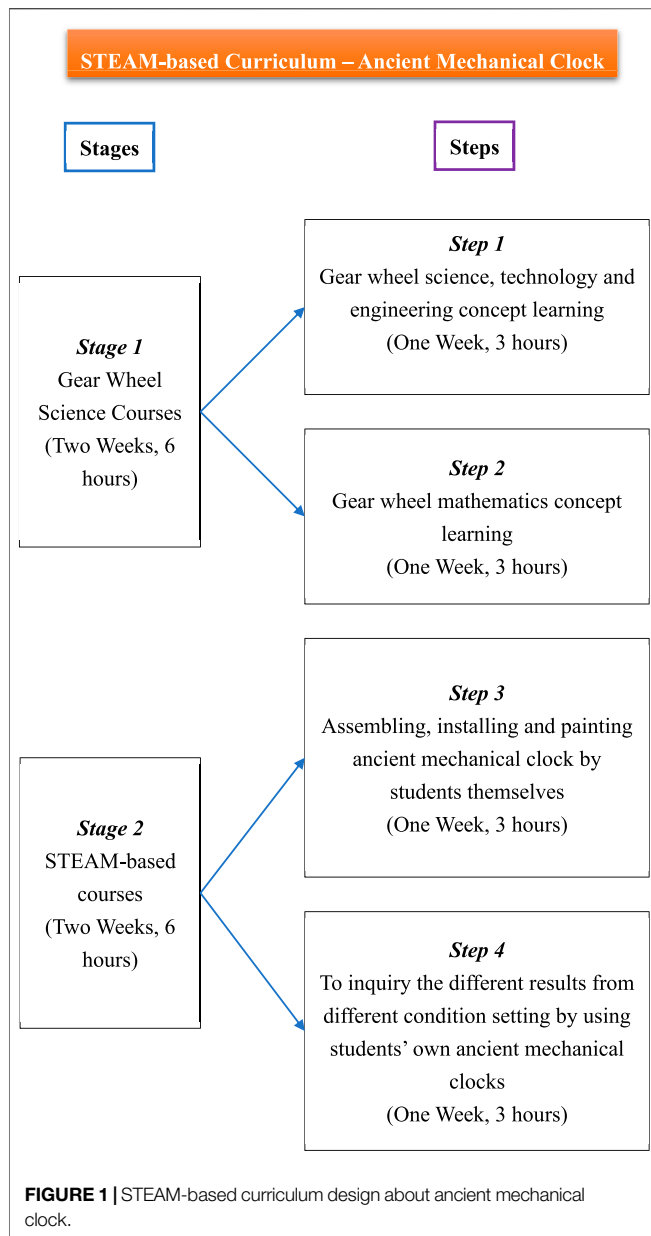
This study hypothesized that the whole STEAM-based curriculum could improve junior high school students' scientific creativity when changing the sequence of course stages. Besides, this study also hypothesized that in the two stages of the STEAM-based curriculum, the STEAM-based stage of the course plays an important role and more effectively improves students' scientific creativity.

There are a few scientific constraints to this study. All participants in this study write down their responses to the scientific creativity test at the same time in class. However, if the number of responses is low, this study would be unable to establish whether this outcome is due to a lack of interest on the side of students or whether they do not have enough motivation to complete the test. In other words, all data on the exam paper that contains words will be counted.

## MATERIALS AND METHODS

### Participants

This study was conducted at an urban junior high school in Taiwan. A total of 62 junior high school students ( $n = 62$ , 35 males, 27 females; mean age  $\pm$  SD = 14.2  $\pm$  0.4 years) participated and were divided into a control group ( $n = 31$ , 17 males, 14 females; mean age  $\pm$  SD = 14.2  $\pm$  0.4 years) and an experimental



group ( $n = 31$ , 18 males, 13 females; mean age  $\pm$  SD =  $14.3 \pm 0.5$  years). All participants were asked to complete the Scientific Creativity test (Hu and Adey, 2002) before the whole course, after the first stage of the course, and after the second stage of the course. However, the two groups of students went through different stage designs. The curriculum design details will be introduced in the next section.

## Research Design and STEAM-Based Curriculum Design

The aim of this study is to explore the effectiveness of a STEAM-based curriculum on junior high school students' scientific creativity. The main topic of the STEAM-based curriculum is about an ancient mechanical clock which was designed and

produced by the authors' team. To understand the complex ancient mechanical clock, the students need to learn about the gear wheel science, technology, engineering, and mathematics concepts. Besides, this study added STEAM-based courses to enhance students' understanding of the whole concepts of the ancient mechanical clock. All students needed to assemble, install and paint their own ancient mechanical clock by themselves, and inquiry the different results from different condition setting by using students' own ancient mechanical clocks. Hence, this study designed a STEAM-based curriculum which was included in step 2 and step 4 (Figure 1). The curriculum design was reviewed and confirmed by three experts (male = 2, female = 1; all experts have majored in science education).

Although all students went through these two stages of the curriculum, this study wanted to clarify both the influences of STEAM-based courses on students' scientific creativity and which kind of sequence of course stage design is more effective in improving students' scientific creativity. To find the possible results of the core research questions, this study adopted a counterbalance design. This design is divided into two stages: stage 1 (gear wheel science courses with two steps) and stage 2 (STEAM-based courses with two steps). In particular, in step 3, students can connect their interdisciplinary knowledge and experiences to generate new ideas by assembling and installing the ancient mechanical clock themselves; additionally, by painting their clock, students' arts abilities are demonstrated and trained, from which the combination of the arts with STEM subjects becomes STEAM and students' scientific creativity will be developed.

The control group students were asked to join stage 1 first and then join stage 2. This kind of curriculum design helps students construct their scientific concepts first and then guides them to integrate their concepts by joining STEAM courses. In contrast, the experimental group students were asked to join stage 2 first and then stage 1 (Figure 1). This kind of curriculum design helps students learn the interdisciplinary knowledge in STEAM courses by themselves, and then guides them to generalize their scientific concepts. Photos of students participating in the study are shown in Figure 2.

The control group style (stage 1 to stage 2) construct students' scientific concepts first and then guides them to integrate their concepts by joining STEAM courses. The experimental group style (stage 2 to stage 1) leads students to trial and error by themselves in STEAM courses and then guides them to organize their scientific concepts.

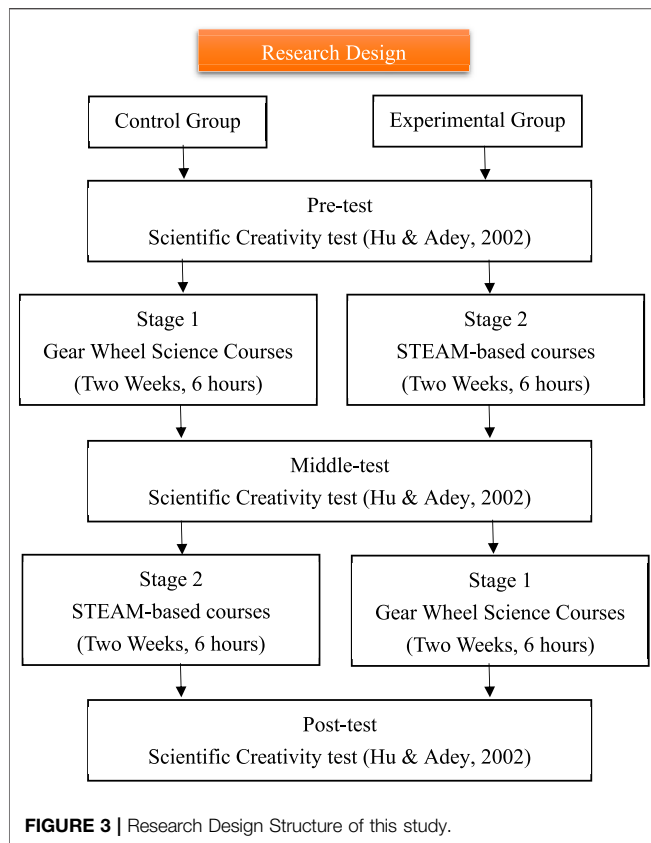
As can be seen in Figure 3, both the comparison of the pre-test and middle-test and the comparison of middle-test and post-test was used to investigate the research question "the efficiency of STEAM-based courses on students' scientific creativity". Meanwhile, the comparison of the pre-test and post-test was used to reflect the exploring about research question "which kind of sequence of course stage design is more effective to improve students' scientific creativity?"

## Instrument and Scoring

This study adopted Scientific Creativity Test (Hu and Adey, 2002) to be the main instrument, and the details of the Scientific



**FIGURE 2 |** Photos of students participating in the study.



Creativity Test are shown in **Table 1**. This test was re-tested and verified by the Huang and Wang (2019), and the results indicated that both the students’ science performances and creativity could reflect their performance creativity well.

In Hu and Adey’s research, the Scientific Creativity Test was also used to explore high school students’ scientific creativity, and the reliability reached Cronbach’s  $\alpha$  0.89. This study translated the test into Chinese and retested it on junior high school students ( $n = 82$ , 38 males, 44 females; mean age  $\pm$  SD = 14.1  $\pm$  1.1 year) in Taiwan, and the revised reliability reached Cronbach’s  $\alpha$  0.87.

- 1) Fluency score: to count all of the separate responses given by the subjects, regardless of the quality.
- 2) Flexibility score: to count the number of approaches or areas used in the answer.
- 3) Originality score (item 1–4/item5/item6/item7): If the probability of a response was less than 5% of all responses, we gave it 3/2/4/5 points; if the probability of a response was from 5 to 10% of all responses, we gave it 2/1/2/3 point; if the probability of a response was greater than 10% of all responses, we gave it 1/0/0/1 points.

There were three professional experts who read all students’ answers and gave the scores of fluency, flexibility, and originality individually. Then, they read the other two experts’ scores, and then provided their comments or modified their scores. These three experts reached a common consensus for reviewing three times.

## RESULTS AND DISCUSSION

This study aims to explore the effectiveness of a STEAM-based curriculum on junior high school students’ scientific creativity. There are two main research questions in this study, which were “the efficiency of STEAM-based courses on students’ scientific creativity” and “which kind of sequence of course stage design is more effective to improve students’ scientific creativity?”.

On the whole, the results from **Table 2** show that not only all participants, but also the control group and the experimental group got significantly higher scores of scientific creativity after the whole STEAM-based curriculum than before. This result supports that the curriculum design in this study could improve students’ scientific creativity.

The result could be supported by previous studies which mentioned that a multi-disciplinary approach project-based design STEAM curriculum could improve students’ creativity (Ngo and Phan, 2019; Ozkan and Topsakal, 2021). Further, Ozkan and Topsakal’s research found that a STEAM design program can enhance students’ verbal and numerical domain-relevant creativity, and this study confirms that the STEAM-based curriculum can improve students’ scientific creativity.

**TABLE 1 |** Scientific creativity test (Hu and Adey, 2002; 2003; Huang and Wang, 2019).

Items	Contents	Scoring
Item 1: unusual uses	Please write down as many as possible scientific uses as you can for a piece of glass	Fluency, flexibility, originality
Item 2: problem finding	If you can take a spaceship to travel in outer space and go to a planet, what scientific questions do you want to research? Please list as many as you can	Fluency, flexibility, originality
Item 3: product improvement	Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful	Fluency, flexibility, originality
Item 4: scientific imagination	Suppose there was no gravity, describe what the world would be like	Fluency, flexibility, originality
Item 5: problem solving	Please use as many possible methods as you can to divide a square into four equal pieces (same shape)	Flexibility, originality
Item 6: science experiment	There are two kinds of napkin. How can you test which is better? Please write down as many possible methods as you can and the instruments, principles and simple procedure	Flexibility, originality
Item 7: product design	Please design an apple picking machine. Draw a picture, point out the name and function of each part	Flexibility, originality

The definition of scoring (Hu and Adey, 2002; 2003; Huang and Wang, 2019).

**TABLE 2 |** The comparison table of pre-test and post-test data.

Group	Pre-test (mean ± SD)	Post-test (mean ± SD)	t	p
Control group (n = 31)	57.26 ± 15.67	72.19 ± 15.43	-5.27	<0.001
Experimental group (n = 31)	56.74 ± 20.86	70.77 ± 18.22	-6.71	<0.001
Total (n = 62)	57.00 ± 18.30	71.48 ± 16.76	-8.29	<0.001

**TABLE 3 |** The comparison table of counterbalance designed about join STEAM-based courses.

Group	Pre-test (mean ± SD)	Middle-test (mean ± SD)	Post-test (mean ± SD)	t	p
Control group (n = 31)		57.90 ± 17.36	72.19 ± 15.43	-4.90	<0.001
Experimental group (n = 31)	56.74 ± 20.86	63.42 ± 18.07		-4.52	<0.001

(Note: the analysis is comparing the post-test and middle-test data of the control group, and the middle-test and pre-test data of the experimental group).

**TABLE 4 |** The ANCOVA analysis to compare different group students' scientific creativity (n = 62).

Sources	SS	df	MS	F	p	$\eta^2$
Corrected model	8299.97	2	4149.984	27.737	<0.001	0.485
Intercept	7080.840	1	7080.840	47.326	<0.001	0.445
Pre-creativity	8268.742	1	8268.742	55.265	<0.001	0.484
Group	18.445	1	18.445	0.123	0.727	0.002
Error	8827.517	59	149.619			
Total	333944.000	62				

To investigate “the efficiency of STEAM-based courses on students' scientific creativity”, this study compared both the post-test and middle-test data of the control group and the middle-test and pre-test data of the experimental group (the research design is in **Figure 3**; the result is in **Table 3**).

Since the control group joined the STEAM-based courses in stage 2 and the experimental group joined the STEAM-based courses in stage 1, this analysis compared the post-test and middle-test data of the control group, and the middle-test and pre-test data of the experimental group. The results from **Table 3** demonstrate that both the control and experimental groups got significantly higher scores after joining the STEAM-based courses than before, no matter what the last courses is. This finding could initially prove that the STEAM-based courses in this study are helpful for improving junior high school students' scientific creativity.

Ugras (2018) indicated that the STEM education approach is teaching individuals to establish the mesh network from interdisciplinary knowledge, behavior, belief, skills, and action and to prepare their problem-solving abilities for real life. To go back to look closely at the contents of the scientific creativity test (Hu and Adey, 2002), we can find that most items of scientific creativity test are close to real-life problems such as “Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful” (Hu and Adey, 2002). This might be a reason to explain why the

students' scientific creativity performances could be significantly improved by joining STEAM-based courses.

Next, this study investigated which kind of sequence of course stage design is more effective to improve students' scientific creativity. There are two kinds of curriculum design in this study (**Figure 2**). The first one is used on the control group, and the students need to join stage 1 (gear wheel science courses) first and then join stage 2 (STEAM-based courses) second. This kind of curriculum design constructs students' scientific concepts first and then guides them to integrate their concepts by joining STEAM courses. The second design was used on the experimental group, and the students need to join stage 2 first, and then stage 1 s. The curriculum design leads students to inquire by themselves in STEAM courses and then guides them to organize their scientific concepts. Which kind of sequence is better for improving junior high school students' scientific creativity?

**Table 4** indicates that there are no significant differences between the control and experimental groups after they had joined the STEAM-based curriculum than before. In other words, the different sequence of courses design did not affect the students' final performance of scientific creativity. Following up, this study analyzed different group students' performance of scientific creativity in different stages.

In **Table 5**, the results show that the control group students did not get significantly higher scores in stage 1, which means the control group students did not perform higher scientific creativity after joining gear wheel science courses, compared to before. But the control group students got significantly higher scores in stage 2, which indicates that the control group students performed more scientific creativity after joining STEAM-based courses, compared to before. Unlike the control group, the experimental group students performed significantly higher scores before joining the course in both stage 1 and stage 2. These results imply that the STEAM-based courses might help students maintain or continue their scientific creativity ability. It demonstrates that the research hypothesis given by this study

**TABLE 5** | Different group students' performance of scientific creativity in different stages (control group  $n = 31$ ; experimental group  $n = 31$ ).

Group	Frequencies of stage	Test 1 (mean $\pm$ SD)	Test 2 (mean $\pm$ SD)	$t$	$p$
Control group	Stage 1 (Pre-test—Middle-test)	57.26 $\pm$ 15.67	57.90 $\pm$ 17.36	0.91	0.371
	Stage 2 (Middle-test—Post-test)	57.90 $\pm$ 17.36	72.19 $\pm$ 15.43	4.90	<0.001
Experimental group	Stage 2 (Pre-test—Middle-test)	56.74 $\pm$ 20.86	63.42 $\pm$ 18.07	4.52	<0.001
	Stage 1 (Middle-test—Post-test)	63.42 $\pm$ 18.07	70.77 $\pm$ 18.22	5.66	<0.001

(Note: stage 1 is gear wheel science courses; stage 2 is STEAM-based courses).

is appropriate, that the entire STEAM-based curriculum might boost junior high school students' scientific creativity when the sequence of course stages is changed. The STEAM-based stage courses, in particular, play an important role in the two stages of the STEAM-based curriculum and more effectively foster students' scientific creativity.

Thuneberg et al. (2018) indicated pre-knowledge was significantly influenced by creativity. That means constructing students' scientific concepts first or generalizing students' science knowledge after trying to find out by themselves might cause different results in fostering students' scientific creativity. This could support that the different curriculum design sequences may cause different advancing effects on students' scientific creativity. Moreover, Torrance (1990) mentioned that imagination and breaking through stereotypes would be the most important factors in improving human creativity. In the control group, the students were asked to join gear wheel science courses in the first stage. This kind of scientific knowledge might be a kind of "stereotype" and might be the reason why the control group students did not show significant differences in scores of scientific creativity in the first stage. However, these implications and hypotheses should be confirmed by further studies.

According to Perignat and Katz-Buonincontro (2019), a small group of scholars consider creativity to be an inherent aspect of the arts; however, the majority of authors argue that creativity is inherent in all disciplines, not just the arts, as it is commonly perceived. That means creativity can be expressed and developed through all aspects of STEAM education, not just the arts. This highlights the importance of all the different aspects of STEAM education in developing creativity in students. Besides that, it is important not to stress the art form or final product over the artistic process itself, and focus on the process of learning through thinking, planning, and creating or performing an artwork rather than on a finished product.

This study used PBL strategies to design a two-stage STEAM-based curriculum and showed its effectiveness in enhancing students' creativity. However, the use of other teaching strategies such as problem-solving learning, programming learning, etc. in STEAM education is also likely to have a positive impact on student creativity (Bicer et al., 2017; Noh and Lee, 2020; Perignat and Katz-Buonincontro, 2019). Therefore, further research and application of these teaching strategies, or the combination of active teaching strategies together, is necessary for the future.

## CONCLUSION AND SUGGESTION

This study aims to investigate the effectiveness of a STEAM (Science, Technology, Engineering, Arts, Mathematics) -based curriculum on junior high school students' scientific creativity. The two core research questions are as follows: 1) What are the influences of STEAM-based courses on students' scientific creativity? 2) Which kind of sequence of course stage design is more effective to improve students' scientific creativity?

The main topic of the STEAM-based curriculum in this study is about an ancient mechanical clock that was designed and produced by the authors' team. Further, the main concept of the ancient mechanical clock is about a gear wheel. A counterbalance design was used in this study. The control group joined gear wheel science courses first and joined STEAM-based courses second. In contrast, before joining the gear wheel science courses, the experimental group first joined the STEAM-based courses.

Based on the data analysis, the results in this study show that the whole STEAM-base curriculum could improve junior high school students' scientific creativity, no matter which kind of sequence is used in the course stage design. Besides, the results support that the STEAM-based courses in this study could improve junior high school students' scientific creativity.

Although the results from ANCOVA analysis demonstrate that there are no significant differences between the control group and experimental group students' scientific creativity performances after joining the whole STEAM-based curriculum, the results in this study show that the students did not improve their scientific creativity after the gear wheel science courses but before STEAM-based courses. In other words, these students' scientific creativity has been induced in only one stage (STEAM-based courses stage). However, the students who joined STEAM-based courses first could improve their scientific creativity in both stage 1 (gear wheel science courses stage) and stage 2 (STEAM-based courses stage).

The results imply that the STEAM-based courses might help students maintain or continue their scientific creativity ability. This study suggests further research to diversify the contents of STEAM-based curriculums is not limited to using available kits but can encourage and require students to solve problems in study and life with their interdisciplinary knowledge and skills. Not only that, in addition to quantitative research, qualitative research through student feedback can also help better understand students' scientific creativity. Alternatively, lengthening the research time or delaying the posttest may also be considered.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the National Kaohsiung Normal University Human Ethic Committee. Written informed consent to participate in this study was provided by the participants'

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