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The effect of an interdisciplinary STEM course on children's attitudes of learning and engineering design skills

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Abstract

The study aimed to investigate the effect of an interdisciplinary STEM course on children's attitudes of learning and engineering design skills. A total of 449 elementary school children in China were recruited from three different grade levels (i.e., second, fourth and sixth grade) to participate in this study. All participants attended a weekly interdisciplinary STEM course for two consecutive semesters. In order to understand how an integrative STEM curriculum interplayed with participants' attitudes of learning and engineering design skills, we conducted two measures to assess the results: the attitude measure (i.e., the attitude of learning questionnaire) and the outcome measure (i.e., the STEM knowledge assessment and the scenario design assessment). Meanwhile, pre-and-posttests were implemented for each measure when comparing the differences in learning. Our findings revealed that an interdisciplinary STEM course led to positive changes in children's attitudes of learning, yet its effect on different grade levels could vary depending on children's cognitive development. In addition, interdisciplinary learning experiences significantly improved second and fourth graders' engineering design skills, particularly in the scenario design assessment. Lastly, we summarized the relationship between one's attitudes of learning and engineering design skills along with its educational implications.

Keywords Interdisciplinary STEM curriculum · Attitudes of leaning · Engineering design skills · K-12 education

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Introduction

Children nowadays are situated in a multidisciplinary society where learning is no longer confined to the mastery of one single academic subject. They need to be equipped with capabilities and insights to apply multiple knowledge sources at the same time to deal with ever-changing problem scenarios (Bybee 2013). This idea of gaining integrative learning experience challenges children to combine the knowledge they have acquired in multiple classroom settings to one single problem scenario and implement solutions by applying what they already know to what they are expected to learn. Having to rethink and reconstruct their thinking process also guides children to combine what they have learned in seemingly separate academic domains in order to understand and solve problems, and this was well-reflected in the Science, Technology, Engineering, and Mathematics (STEM) education. Although the four STEM subjects appear to be distinctive in content knowledge, their applications in real-world situations are inseparable. For instance, to design an automatic bird feeder, a child needs to understand knowledge from multiple disciplines, such as Science (e.g., investigating birds' food intake), Technology (e.g., setting up an automatic monitoring program), Engineering (e.g., designing the physical structure of the feeder,) and Mathematics (e.g., calculating frequency of feeding that would be required). The key lies in developing an interdisciplinary perspective in problem solving since the thinking skills required for each STEM subject are transferrable to the other STEM subjects. In other words, children should be able to develop an insight into analyzing and solving problems by blending the four strands and using them as one whole body of knowledge.

In response to the interdisciplinary STEM education, China has recognized the importance and urgency to develop an integrated STEM curriculum at K-12 level. The Ministry of Education in China has officially announced STEM curriculum standards into elementary school curriculum since 2017. Major cities such as Beijing, Shanghai and Shenzhen first joined the educational movement by implementing new STEM curriculum into routine education. Although these curriculum standards seem to have been tailored for Science education, their establishment particularly highlighted the significance of blending science education with other academic subjects, such as mathematics and technology, to provide integrated STEM literacy skills for children. This emphasis on the curriculum and the integration of skills has been supported by findings in previous studies, in which it was claimed that offering integrated STEM education improves children's, higher-order thinking skills, and even engineering design skills (Carlson and Sullivan 2004; Estapa and Tank 2017; Furner and Kumar 2007). Interdisciplinary learning experiences allow children to recognize differences between individual subject areas and form meaningful connections among different areas for effective thinking and enhanced problem-solving skills (Bybee 2013; Ivanitskaya et al. 2002). However, despite the aforementioned trends and benefits of an interdisciplinary STEM curriculum, children still struggle with applying an integrative STEM perspective to solve everyday problems.

This struggle for children was further explained by the difficulties of generating a holistic understanding of real world problems with respect to the four STEM subjects both at conceptual and engineering design level. At conceptual level, it was challenging for children to integrate knowledge from multiple domains into one unified realm because they hold different learning attitude toward the four STEM subjects. One's learning attitude determined his/her level of engagement in learning and the amount of effort put into a learning task. Varied learning attitude in a STEM classroom could lead to varied path of thinking, perceived learning self-efficacy and choices of problem-solving strategies

(Chabalengula and Mumba 2017; Christensen et al. 2014). For instance, a child with positive learning attitude in mathematics would meticulously investigate a real world problem by applying adequate mathematical methods yet in the meantime ignore the engineering design or technological compatibility aspect of the problem. Therefore, identifying the relationship between one's learning attitude and outcome was crucial for STEM educators. At engineering design level, engineering design practices engaged children in problem-solving activities by enhancing their understanding of how STEM knowledge can be applied to the design and implementation of their conceptual solutions. An interdisciplinary STEM problem requires solid design skills to verify the solution through visual illustrations (NRC 2014; Fan and Yu 2017). The engineering design activity generally asked the learner to convert abstract, conceptual solutions into concrete, visual representations. Children might have difficulties in precisely depicting the solution in details to reexamine the original solution for necessary changes. In addition, an engineering design activity might involve spatial thinking and communication of spatial concepts, which added another layer of difficulty to the learner. Consequently, the whole design task can be perceived as a process to externalize a child's personal representation of the interrelationship between the problem scenario and the proposed solution based on STEM knowledge.

These findings guided us to recognize the importance of identifying children's attitudes of learning and engineering design skills in dealing with an interdisciplinary STEM problem. An investigation on children's attitudes of learning and their STEM learning outcome seems imperative. Meanwhile, the development of engineering design skills played a significant role when understanding how children apply the four STEM subjects into problem solving practices. Thus, the current study aimed to investigate the effect of engaging children in interdisciplinary STEM problem solving on their learning attitudes and engineering design-skills. We were particularly interested in knowing the evolution of learning attitude in a STEM classroom and how interdisciplinary STEM learning experiences resulted in changes in engineering design skills. We wondered whether children could benefit from an interdisciplinary STEM course by integrating knowledge in four separate subjects into one integrative view for problem solving. The following research questions were proposed to guide the study:

1. What was the evolution of children's learning attitude in an integrated STEM course?
2. Did an integrated STEM course have an effect on children's knowledge development in each of the four STEM subject?
3. Did an integrated STEM course have an effect on children's engineering design skills during problem solving?

An interdisciplinary perspective on STEM curriculum

Integrating the four STEM disciplines

Researches on the four strands of STEM education have moved from a disciplinary perspective to an interdisciplinary perspective (Johnson 2013; Roehrig et al. 2012; White 2014). Under this integrative STEM education framework, learners are supposed to acquire the knowledge, skills, and beliefs that are collaboratively constructed at the intersection of more than one STEM subject area (Corlu et al. 2014). The practice of combining multiple STEM subjects into one discipline was also reflected in the literature of curriculum integration, where researchers emphasized the importance of making STEM curriculum to be connected to real-life, everyday situations for deeper learning and thinking (Kelley and Knowles 2016). Learners were thus situated within a broader learning context to examine their understanding of STEM knowledge.

Although educators have been dedicated to promoting an integrated STEM curriculum for young students, the four subjects received different levels of educational attention. Meanwhile, the interconnectedness of the four subjects had yet to be clearly reflected in the curriculum. Ideally, the ultimate goal of STEM education was to develop one's cognitive learning capabilities of co-dependent science and mathematics in order to produce advances in engineering and technology (Hernandez et al. 2014). Science and mathematics were at the forefront of STEM education, mainly because these two subjects were the most recognizable and most people can relate to them, while technology and engineering belonged to specialized fields that were relatively underrepresented (White 2014). This was partly due to the common impression that science and mathematics appeared to be an effective indicator of children's intellectual development or academic achievement. Science and mathematics represented the foundations of scientific knowledge while engineering and technology represent the abilities and techniques to implement problem-solving solutions. Science and mathematics require learning the concept, the procedure, the discipline and the application of practical knowledge in relevant scenarios. Engineering and technology require more hands-on design experiences, illustrative visual examples and pragmatic problem solving skills and sometimes these practices should be situated in the context of one's everyday experiences. Researchers argued that mathematics and sciences were knowledge that can be applicable to the problem solving practice of technology and engineering design ideas (Kirschenman and Brenner 2010). For instance, when real world problems mixed mathematics with engineering knowledge, learners needed to first figure out the mathematical patterns among numbers and then transformed it into an action plan to delineate a particular design goal based on engineering theories (Flegg et al. 2012). The result of problem-solving depended on whether learners were able to effectively align their perceived certainty in one subject area with perceived certainty in other subject area during the problem-solving process (Billingsley et al. 2016).

Assessing learning in a STEM classroom

Aiming to understand how children developed an integrative view of STEM knowledge, we reviewed findings in similar educational contexts that guide children to link together scattered knowledge in problem solving. One common approach was to engage children in design-based learning activities. For instance, in engineering courses, students' design and planning capabilities were essential to their problem-solving skills. These hands-on design experiences allowed learners to not only demonstrate their thoughts through external representations but also testify their assumptions during design activities. Therefore, in previous studies, design-based activities served as a common pedagogy to promote learning across the four STEM disciplines (Guzey et al. 2017; Karahan et al. 2015; Lantz 2009). Fan and Yu (2017) examined students' design performance in an integrated STEM classroom by investigating how the students dealt with different types of knowledge (i.e., conceptual knowledge and procedural knowledge) and applications of higher-order thinking skills during design activities. They concluded that engineering design experiences encourage students to combine relevant STEM knowledge, thereby improving their cognitive learning skills in terms of the representation, prediction, and analysis of problems. In another study by Billingsley et al. (2013), they explored middle-school students' insight of learning by exposing them to two seemingly different learning areas for deeper thinking and self-reflection. They conducted questionnaires and interviews to guide participants to reflect upon the conceptual contradictions between their scientific knowledge and religious beliefs. Due to the fact that many participants failed to develop an insight into the relationships between nature, science, and religion, it was suggested that children needed more learning opportunities to understand the interconnectedness between multiple disciplines.

In order to examine learners' interdisciplinary thinking skills in STEM education, another approach was to concentrate on the general learning and teaching principles from cognitive science (Hernandez et al. 2014). In fact, the framework of this approach was based on de Miranda's (2004) work in good instructional design practices, in which three abilities were summarized to investigate one's performances of learning in an interdisciplinary classroom, including: (1) the ability to engage actively with the learning process and content, (2) the ability to reflect on and connect existing structures of knowledge to further their learning, and (3) the ability to interact with teachers, peers, and the source of knowledge to advance their thinking. These abilities highlighted the importance of active engagement, reflective thinking and peer collaboration for effective integrated curriculum. On the other hand, children's learning performances in an interdisciplinary field were closely related with their attitudes of and attitude toward learning. In general, one's attitude of learning was closely related with his/her own interpretations or viewpoints of the specific learning task. Thus, varied attitudes of learning could lead to significant changes in one's learning outcome in a STEM classroom (Christensen et al. 2014). As children's attitudes of learning were changing over time and could vary from subjects to subjects, investigating one's learning attitudes helped researchers understand how learners attributed their efforts to academic achievements. Though leaners' attitudes of learning did not necessarily have a positive relationship with their achievements, changes in their attitude and attitudes toward each STEM subject were shown to be predictive of their learning outcomes (Reynolds and Walberg 1992). Some studies concluded that when children held positive attitudes toward a science course, they became more engaged and motivated in the pursuit of scientific knowledge (Murphy and Beggs 2001); others indicated that it was the learning topic's level of relevance with learners' everyday experiences that determined their curiosity and motivation of learning (Agranovich and Assaraf 2013; Osborne et al. 2003). Moreover, there were other criteria worth investigating when exploring one's attitudes of learning in s STEM classroom. Researchers pointed out that learners' attitudes about peer collaboration in a science classroom could lead to mixed learning results. Although peer discussions and collaborative brainstorming appeared to be conducive to the cultivation of a learning community (Fields 2009), in Agranovich and Assaraf (2013)'s research, they claimed that self-readings and customized guidance in a STEM classroom resulted in deeper thinking and, in turn, improved students' meta-cognitive learning skills. Aside from peer collaboration, the inclusion of hands-on design experiences in a STEM classroom significantly improved students' learning performance (Klahr et al. 2007; Stohr-Hunt 1996). For instance, engineering drawings were found as an effective venue to engage learners in reflecting on the engineering design process and complex structures, which resulted in positive attitude of learning toward the content knowledge (Azodo 2016). Hands-on practices, direct manipulations with the learning content could result in enhanced motivation of learning and willingness to further explore the learning content, which also brought positive learning attitude toward that learning content. In sum, the review of literature revealed a number of criteria that had been investigated in either science or engineering classroom to understand students' attitude of learning. These criteria, including problem solving, peer collaboration and hands-on design, might be applicable to the present study to understand changes in children's learning attitude in a STEM classroom.

Method

Participants

A total of 449 elementary school children from a public elementary school in Beijing participated in the study. All participants were from three grade levels: second graders (n = 182, aged between 7 and 8 years old), fourth graders (n = 166, aged between 9 and 10 years old) and sixth graders (n = 101, aged between 11 and 12 years old). Participation was completely voluntary and based on prior informed consent, so the possibility of a self- selection bias cannot be excluded. Since the entire study was held during the required, weekly STEM courses at school, none of the participant dropped out during the study. Each participant attended this 50 min STEM course every week for one entire semester, during which they learned practical knowledge from the four STEM subjects in order to solve real-world problems (i.e., how to design of a vital capacity calculator). Detailed demographic data was presented in Table 1.

Design and procedure

This was a 1-year (i.e., two full semesters), quasi-experimental study with participants from three grade levels (i.e., second, fourth and sixth grade). The treatment was the required STEM course held every week for 16 consecutive sessions. Different curriculum content and assessment was designed and implemented for participants in different grade levels, meaning a total of six learning themes were created in this study, as shown in Table 2. Each learning theme was designed based on real world problem scenarios that required participants to apply and integrate the four seemingly scattered STEM subjects to form an integrative perspective in order to solve the problems. Besides, all participants were asked to fill out an attitude of learning questionnaire and complete two assessments before and after the treatment. Since the participant belonged to three grade levels, a different instructor was assigned for each grade. All instructors were trained ahead of time in order to implement a problem-based instructional approach throughout the treatment.

Table 1 Participants' demographic data

Grade level	Sex		
	Male	Female	Total
G1: second graders	84 (46%)	98 (54%)	182
G2: fourth graders	99 (60%)	67 (40%)	166
G3: sixth graders	67 (66%)	34 (34%)	101
Total	250 (56%)	199 (44%)	449

Table 2 An overview of learning themes for each grade

Semester	Level		
	Second graders	Fourth graders	Sixth graders
One	Theme: Roads and Trails Design task: *How to design roads/trails between the local zoo and the museum?*	Theme: Birds Feeder Design task: *How to design a roach trapper at home?*	Theme: The construction of bridges Design task: How to design a bridge sit across the river?
Two	Theme: The design of worm bins Design task: *How to build up a home suitable for crickets?*	Theme: Vital capacity Design task: *How to create an artifact to measure one's vital capacity?*	Theme: Soil erosion Design task: *How to plan and implement a soil erosion control system?*

Measures

We compared and investigated participants' learning outcome with two measures: the Attitude Measure and the Outcome Measures. Both measures were administered at the beginning and the end of each treatment. The Attitude Measure comprised of a questionnaire with 15 Likert scale questions that investigated participants' attitudes of learning. The Outcome Measure consisted of two types of assessment (i.e., the STEM knowledge assessment and the scenario design assessment) that investigated participants' capabilities to apply STEM knowledge to solve real-world problems.

The Attitude Measure was designed and developed under a multi-stage framework. We first reviewed relevant literature to identify issues related to elementary school children's attitude in a STEM classroom. There was a huge body of researches discussing how one's attitude interacted with his/her learning outcome in STEM education (Plant et al. 2009; Ragusa and Lee 2012; Wendell and Rogers 2013). With the review results, we then narrowed down the search by considering what was core to a problem-based, design-intensive and interdisciplinary STEM curriculum. In the final step, we concluded the following five criteria to understand changes in one's learning attitude: (1) problem-solving, (2) peer collaboration, (3) critical thinking, (4) engineering design skills and (5) career orientation. A questionnaire was developed based on the five criteria; each criterion consisted of two to three questions. All questions were designed according to the literature concerning children's core skills and capabilities while engaging in design-based activities in a STEM classroom. The complete list of survey questions for each grade level was included in the "Appendix". The Cronbach's Alpha reliability test was computed to estimate internal consistency reliability of the questionnaire, indicating a good internal consistency coefficient, as shown in Table 3. It was notable that the questionnaire for second graders was tailored to address their cognitive limitations in answering the attitude of learning questions. For instance, we switched to a three-point Likert response format for second graders given their intellectual growth. Besides, the critical thinking dimension was removed for second graders because such questions might seem too abstract for them.

The Outcome Measure consisted of two types of assessment: the STEM knowledge assessment and the scenario design assessment. The STEM knowledge assessment consisted of 11 close-ended questions to investigate participants' understanding of STEM knowledge; the scenario design assessment consisted of a real world STEM problem that required participants to first analyze the problem and then outline their solutions through drawings as well as annotations.

Table 3 The questionnaire for the attitude measure

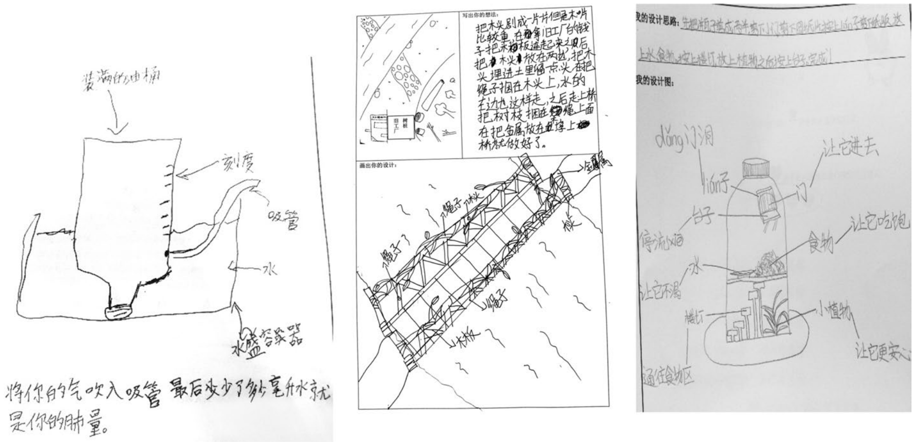
Dimensions	Grade level		
	Second	Fourth	Sixth
Problem-solving	2 questions	3 questions	3 questions
Peer collaboration	2 questions	3 questions	3 questions
Critical thinking	None	3 questions	3 questions
Engineering design skills	2 questions	None	None
Career orientation	2 questions	3 questions	3 questions
Total questions	8	12	12
Cronbach's Alpha	0.684	0.741	0.783

An example of participants' drawings was presented in Fig. 1. When analyzing the drawings, a self-made three-point rubric scale was developed and implemented for each learning theme. Rubric was used because it allowed us to evaluate participants' drawings based on a sum of various dimensions of learning rather than a single, definite score. We then divided the drawing task into three dimensions to represent different stages in time: the before, middle and after stage. The before stage examined how participants analyzed the problem to elicit a conceptual understanding; the middle stage examined participants' engineering design skills to visualize the ideas in detail; the after stage examined whether the illustrated solution successfully addressed the original problem and its causes. Therefore, each rubric had three evaluation criteria to reflect the three-staged model: (1) problem analysis (2 points), (2) hands-on design capabilities (3 points) and (3) practicability of solutions (3 points). To ensure agreement among raters, we computed the Kendall's coefficient of concordance among the three raters. In Table 4, it was found a good agreement of raters was achieved.

Results

The effect of the STEM course on the attitude measure

An independent *t* test was implemented to analyze the results of the attitudes of learning questionnaire. Since changes in one's attitudes of learning often took a longer time, we compared the result under two conditions: T1 versus T3 and T2 versus T3. T1 denoted the pretest score of the first semester (i.e., the fall semester); T2 denoted the posttest score of the first semester; T3 denoted the posttest score of the second semester (i.e., the spring semester). It was found that fourth graders showed significant differences in critical thinking ($p < 0.01$) and career orientation ($p < 0.01$) for both T1 versus T3 and T2 versus T3 conditions; sixth graders showed significant differences in peer collaboration ($p < 0.05$) and critical thinking ($p < 0.05$), however, this was only found between T1 and T3. An overview of the result was presented in Table 5. For second graders, no significant changes in attitudes of learning were identified after attending an interdisciplinary STEM course.



将你的气吹入吸管 最后变少了多少毫升水就是你的肺量。

写出你的想法：把木头剧成一片片但是木片比较重，在[illegible]旧工厂的钱子把木[illegible]板连起来之后把[illegible]木头[illegible]放在两边，把木头埋进土里留一点头，在把绳子捆在木头上，水的左边也这样走，之后走上桥把树枝捆在[illegible]绳上面在把金属放在[illegible]墩上[illegible]桥就做好了。

我的设计思路：先把瓶子截成两半，剪下小门剪下圆纸片，按上lián子剪纸版，放上水食物，按上楼梯，放上植物之后按上台子，完成！

Fig. 1 Examples of drawings with annotations for the scenario design assessment

Table 4 Kendall’s coefficient of concordance of raters

Grade	Dimensions		
	Problem analysis	Practicability of solutions	Hands-on design capabilities
Second	$W=0.944$, $\chi^2=99.12>\chi^2_{0.99}(35)=57.342$	$W=0.890$, $\chi^2=93.45>\chi^2_{0.99}(35)=57.342$	$W=0.901$, $\chi^2=994.61>\chi^2_{0.99}(35)=57.342$
Fourth	$W=0.948$, $\chi^2=105.23>\chi^2_{0.99}(37)=59.893$	$W=0.804$, $\chi^2=89.24>\chi^2_{0.99}(37)=59.893$	$W=0.651$, $\chi^2=72.26>\chi^2_{0.99}(37)=59.893$
Sixth	$W=0.925$, $\chi^2=88.8>\chi^2_{0.99}(32)=53.486$	$W=0.905$, $\chi^2=86.88>\chi^2_{0.99}(32)=53.486$	$W=0.803$, $\chi^2=77.09>\chi^2_{0.99}(32)=53.486$

Table 5 Results of the attitude measure

Dimensions	Participants		
	Second graders Mean (SD)	Fourth graders Mean (SD)	Sixth graders Mean (SD)
Peer collaboration	T1: 1.64(0.48) T2: 1.68(0.50) T3: 1.68(0.45)	T1: 3.32(0.58) T2: 3.38(0.57) T3: 3.40(0.58)	T1: 3.29(0.635) T2: 3.35(0.736) T3: 3.39(0.57)
	T1–T3: 0.56 T2–T3: 0.00	T1–T3: 1.29 T2–T3: 0.33	T1–T3: 2.417* T2–T3: 0.805
Problem-solving	T1: 1.62(0.54) T2: 1.64(0.55) T3: 1.65(0.58)	T1: 3.33(0.79) T2: 3.29(0.80) T3: 3.28(0.83)	T1: 3.27(0.789) T2: 3.22(0.987) T3: 3.08(1.005)
	T1–T3: 0.47 T2–T3: 0.43	T1–T3: −0.46 T2–T3: −0.16	T1–T3: −1.203 T2–T3: −0.905
Critical thinking	None	T1: 1.08(1.01) T2: 1.57(0.94) T3: 1.76(0.99)	T1: 1.89(0.88) T2: 1.83(1.024) T3: 1.78(0.803)
	None	T1–T3: 7.45** T2–T3: 2.43**	T1–T3: −2.174* T2–T3: −0.699
Career orientation	T1: 1.32(0.65) T2: 1.47(0.57) T3: 1.40(0.68)	T1: 3.14(0.78) T2: 3.12(0.88) T3: 2.84(1.00)	T1: 2.81(1.023) T2: 2.92(0.956) T3: 2.80(1.015)
	None	T1–T3: −4.01** T2–T3: −3.31**	T1–T3: −0.415 T2–T3: −0.751
Engineering design skills	T1: 1.63(0.53) T2: 1.71(0.48) T3: 1.69(0.49)	None	None
t test	T1–T3: 0.85 T2–T3: 0.08	None	None

*Significant at the $p < 0.05$ level; **Significant at the $p < 0.01$ level

The effect of the STEM course on the outcome measure

Results of the STEM knowledge assessment

An independent t-test was implemented to compare the learning differences for the STEM knowledge assessment. For second graders, significant differences were found in Science, Engineering and Mathematics in the first semester and Technology for the second semester (see Fig. 2). For fourth graders, significant differences were identified in Science, Technology and Engineering for both semesters. In Mathematics, significant differences were only seen in the first semester (see Fig. 3). For sixth grader, Engineering and Mathematics yielded significant differences in the first semester while Science yielded significant differences in the second semester (see Fig. 4). It was notable that there was no technology related knowledge in the first semester for the sixth graders because part of the data was corrupted and could not be utilized.

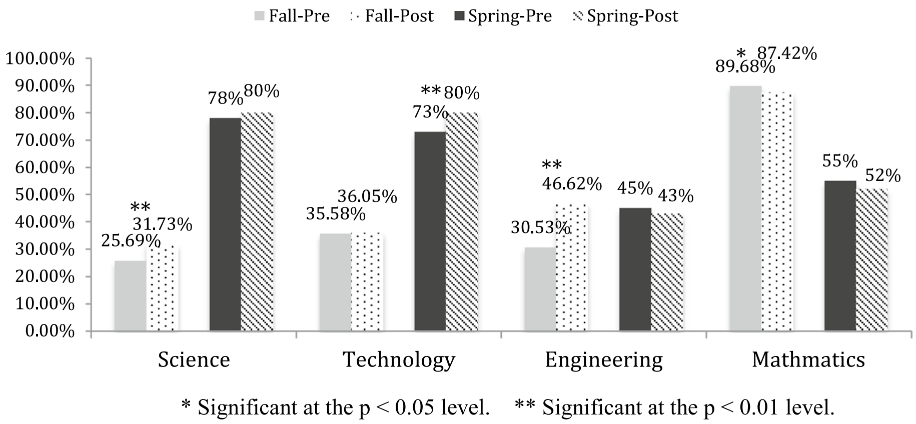


Fig. 2 Changes in 2nd graders' learning outcome for the STEM knowledge assessment

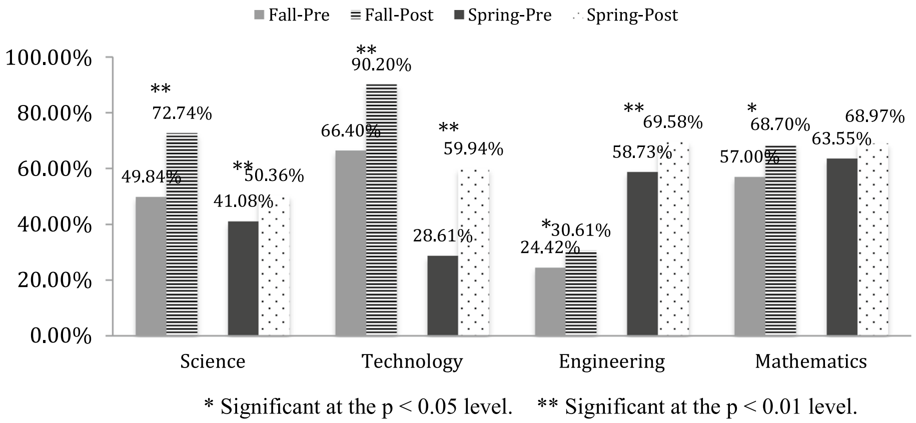


Fig. 3 Changes in 4th graders' learning outcome for the STEM knowledge assessment

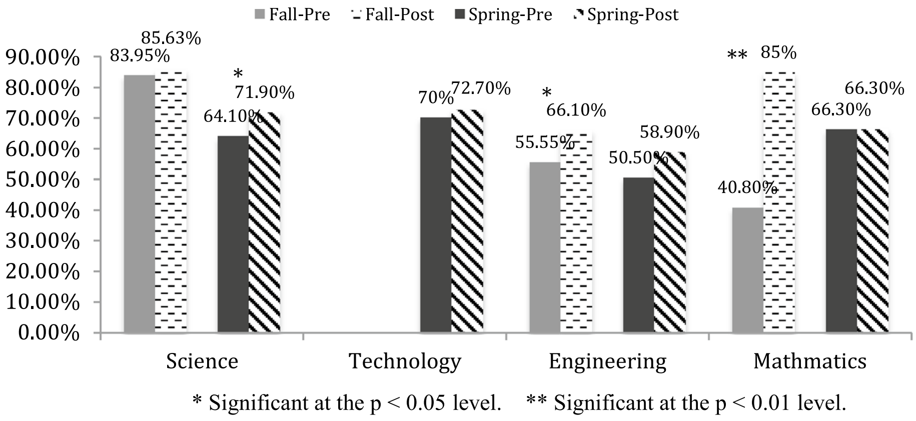


Fig. 4 Changes in 6th graders learning outcome for the STEM knowledge assessment

Table 6 Results of the scenario design assessment (semester one)

Dimension	Participants					
	Second graders M(SD)		Fourth graders M(SD)		Sixth graders M(SD)	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Problem analysis	0.45(0.69)	0.53(0.75)	0.24(0.52)	0.47(0.66)	1.03(0.59)	1.15(0.67)
	t = 1.38		t = −4.75**		t = .1.492	
Practicability of solutions	0.49(0.63)	0.64(0.73)	0.86(0.7)	1.21(0.74)	1.1(0.85)	1.16(0.4)
	t = 2.78*		t = −6.17**		t = 0.46	
Hands-on design capabilities	0.61(0.67)	0.79(0.71)	0.98(0.72)	1.41(0.71)	1.35(0.73)	1.48(0.84)
	t = 3.3*		t = −7.11**		t = −1.23	

*Significant at the $p < 0.05$ level; **Significant at the $p < 0.01$ level

Table 7 Results of the scenario design assessment (semester two)

Dimension	Participants					
	Second graders M(SD)		Fourth graders M(SD)		Sixth graders M(SD)	
	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Problem analysis	0.81(0.90)	1.13(0.92)	1(0.74)	1.54(0.67)	0.96(0.79)	0.93(0.7)
	t = 3.94**		t = −6.98**		t = .332	
Practicability of solutions	0.52(0.76)	0.91(0.80)	0.55(0.68)	1.05(0.71)	1.17(0.97)	0.97(0.91)
	t = 5.51**		t = −7.54**		t = 2.011*	
Hands-on design capabilities	0.43(0.63)	0.66(0.68)	0.87(0.66)	1.19(0.7)	0.97(0.86)	1.44(0.9)
	t = 3.54**		t = −4.95**		t = −5.510*	

*Significant at the $p < 0.05$ level; **Significant at the $p < 0.01$ level

Results of the scenario design assessment

The result of scenario design assessment was analyzed and compared through a self-made scoring rubric. In the first semester, participants in the second grade achieved significant differences of engineering design skills in terms of practicability of solutions ($p < 0.05$) and hands-on design capabilities ($p < 0.05$). In addition, participants in the fourth grade showed significant differences in engineering design skills across all three dimensions ($p < 0.01$). However, no significant differences were identified for sixth graders (see Table 6). In the second semester, as shown in Table 7, a significant difference of engineering design skills was found for both second and fourth graders across all three dimensions ($p < 0.01$). Meanwhile, participants in the sixth grade showed significant differences for practicability of solutions ($p < 0.05$) and hands-on design capabilities ($p < 0.05$).

Discussions and conclusions

In this study, the researchers intended to understand the effect of an integrated STEM course on children's attitudes of learning and engineering design skills when engaging in real-world problems. Through the analysis of pre-and-post assessments, we compared changes in children's attitudes of learning and their engineering design skills for both the STEM knowledge assessment and the scenario design assessment.

Changes in attitudes of learning

When exploring changes in children's attitudes of learning, it seemed the interdisciplinary STEM curriculum indeed resulted in positive changes in one's attitudes of learning on STEM subjects for several dimensions, which was consistent with findings in previous studies (Becker and Park 2011; Shahali et al. 2017). For instance, participants in the fourth grade demonstrated significantly more positive attitudes concerning critical thinking skills while sixth graders' preferences for peer collaboration significantly increased. However, despite all positive changes, we were perplexed to find that fourth graders' interests in finding a STEM related job significantly dropped at the end of the second semester.

Since these significant changes in attitudes occurred mostly for fourth and sixth graders rather than second graders, it occurred to us that asking second graders to reflect on their attitudes of learning could be a bit too abstract given their limited cognitive learning capabilities. It was asserted that the evolution of children's attitudes of learning could vary greatly based on their age and cognitive development (Hess and Wallsten 1987). Otherwise, we might have to adjust the wording or give concrete examples when assessing changes in second graders' attitudes of learning. For fourth and sixth graders, the increased self-awareness in critical thinking and peer collaboration proved that interdisciplinary learning experiences in a STEM course were conducive to changes' in one's attitudes of learning in a positive direction, echoing the findings in relevant studies (Christensen et al. 2014; Guzey et al. 2017; Vennix et al. 2017). One might ask: do positive changes in children's attitudes of learning lead to better engineering design skills in a STEM classroom? Our analysis results showed no definite answer to this question. Take participants in the second grade for example, though their attitudes of learning yielded no significant changes, their engineering design skills for both the STEM knowledge assessment and the scenario design assessment improved significantly. On the contrary, participants in the sixth grade showed significant changes in attitudes of learning on peer collaboration, yet there was no significant difference found in the results of the two assessments for the first semester. Consequently, the STEM course resulted in both positive and negative changes in children's attitudes of learning that might interplay with their engineering design skills. However, there was no evidence substantiating that positive change in one's attitudes of learning for STEM subjects led to improved engineering design skills.

Changes in engineering design skills

Aside from the attitude measure, the outcome measures consisted of two types of assessments to investigate changes in participants' engineering design skills. The STEM knowledge assessment aimed to understand how participants dealt with bounded questions by selecting an answer from the list of options. As we specifically examined the learning outcome from the four STEM subject separately, it was found that, in general, attending this

STEM course helped children achieved a higher mean score across almost every STEM subject. Though participants in each grade level were exposed to different learning themes, the analysis unveiled that second and fourth graders yielded relatively more significant differences in engineering design skills than sixth graders. One possible explanation could be the learning theme's level of relevance to children's everyday life for easier transition from personal experiences to the problem scenario (Agranovich and Assaraf 2013; Osborne et al.2003). For second and fourth graders, the assigned learning themes (e.g., the design of a worm bin and the design of a bird feeder) were a context where children could quickly relate to and form a mental representation of the problem scenario. However, for sixth graders, the learning theme such as the prevention of soil erosion was relatively less engaging to the participant. In other words, when a real world STEM problem was presented in a learning context conducive to children's self-reflections and sense making, they become more capable of developing an insight into the problem.

The scenario design assessment aimed to investigate children's capabilities of using visual representations to demonstrate their knowledge in the problem-solving process. We wondered whether children were able to concretize their thoughts and solutions through drawings and annotations. The analysis examined children's engineering design skills through three aspects that captured the procedural features of design activities: problem analysis, practicability of solutions and hands-on design capabilities. We came to mixed results for the effect of this STEM course on scenario-based design activities. For second and fourth graders, integrated learning experiences significantly improved their engineering design skills across nearly every aspect. Our findings were consistent with the results discussed in previous studies (Fan and Yu 2017; Karahan et al. 2015). However, for participants in the sixth grade, though the mean score in posttest was slightly higher than that in pretest, there was no significant difference found in the first semester. This could be ascribed to participants' limited insights to form a comprehensive understanding of the learning theme. For second graders, it was notable that even though a significant difference in design skills was achieved, most participants still struggled with transforming thoughts into detailed, well-organized engineering design plans because the mean scores across all three aspects were below one point, meaning free drawings without structured guidance could be too difficult for children at the age between seven to eight years old.

Educational implications

The interrelationship between children's attitudes of learning and engineering design skills with real world STEM problems guided us to rethink about the pedagogy and instructional interventions teachers should offer to facilitate effective learning activities. Findings from the current study revealed that children might hold positive attitudes of learning toward STEM subjects, yet their demonstrated engineering design skills didn't seem to be in correspondence with their attitudes of learning. In addition, we recognized that children might hold negative attitudes of learning toward STEM subjects, yet their demonstrated engineering design skills were strong, meaning one's engineering design skills didn't seem to be in a linear relationship with their attitude of learning. In either scenario, it was worthwhile to contemplate the educational implications underlying the settings of the study. Henceforth, we summarized the interrelationship between children's attitudes of learning and engineering design skills in a STEM course as four types (see Table 8 below).

The most ideal condition of learning would be Type one, where learners' attitudes of learning and engineering design skills are in a positive relationship with each other.

Table 8 Relationships between one's perceptions of learning and engineering design skills

Perceptions of learning	Engineering Design skills	
	Strong	Weak
Positive	Type 1	Type 3
Negative	Type 2	Type 4

However, this could also become the most difficult condition to achieve. For Type two learners whose attitudes of learning are negative yet engineering design skills are strong, the possible cause could be due to an examination–oriented learning culture. This might serve as a warning sign for both school administrators and policy makers. Instructional interventions should focus on helping children keep developing their scientific passions and not to be discouraged or manipulated by the evaluation criteria. For learners in Type three who show potentials in learning yet academic achievement is low, more examples about how STEM knowledge is connected in every aspect of life should be presented to the learner. The key lies in how to effectively align learning goals with personal interests for deeper thinking to take place. For children who fall into Type four, a comprehensive investigation on academic performance and learning pattern should be performed in order to understand the appropriate instructional supports to offer.

In sum, this study attempted to unravel how elementary school children within different age groups (i.e., second, fourth and sixth grade) learn and apply STEM knowledge from an interdisciplinary perspective. When evaluating and comparing the learning outcome, we utilized free drawings as a means to understand children's problem-solving process. Free drawings allowed children to easily depict their logical thinking, yet this approach remained challenging for participants who struggled with free drawing or had difficulties generating proper mental representations of practical solutions. Meanwhile, free drawings resulted in additional time and efforts to score the learning outcome, particularly given the number of participants recruited in the study. We did not, however, attempt to deny the practicability of applying one's visual drawings to unpack everyday problems. Instead, we suggested more structured instructional guidance might be needed during the problem-solving activity to not only make this approach more effective but help instructors figure out the depth of thinking and reasoning among participants.

The obtained result could serve as a reference for educators to understand the effect of an interdisciplinary STEM course on children's attitudes of learning and engineering design skills. Changes in both the Attitude Measure and the Design Measures confirmed the effectiveness of using real-world problems to facilitate the learning and thinking of STEM knowledge. Though positive results were gained in general for all participants, the differences in learning among the three grade levels guided us to recognize the cognitive capabilities among children when evaluating their learning outcome with real world problems. In addition, when investigating the results between the two types of assessment tasks, the findings demonstrated how different forms of representations added to the difficulty of STEM problem-solving practices, which could be applied to the design of STEM curriculum and pedagogy. Follow-up studies might expand the type and depth of the assessment tasks to understand how interdisciplinary STEM learning experiences could benefit learning and teaching activities.

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Appendix

Sample questions for Outcome Measure

1. Which of the following approach is most likely to catch ladybugs? Circle the options you think are correct.
    a. Put a piece of baked potatoes on the floor.
    b. Hang a container with sugar water in the air with ample light.
    c. Place an empty box under a flowering plant and then shake the plant.

2. To avoid being bitten by insects, people use technology to produce insect repellents Which of the following methods is an insect repellent method that does not harm the environment and other organisms?

    (1) Use the plants that mosquitoes don't like to make citronella oil
    (2) Spray pesticide inside the room
    (3) Set up mosquito killer lamp

3. In what order do you think the design tasks should be carried out? Write your order on the horizontal line:

    (1) Investigate and design solutions
    (2) Identify problems
    (3) Select materials
    (4) Share results
    (5) Build and test models

4. Below is a picture of an insect. To observe the characteristics of this insects, please circle the correct features in the brackets below, for example, with or without eyes:
   It has (4 6) legs; (yes no) eyes; (yes no) tentacles; (yes no) bones; (yes no) wings.

The learning attitude survey for second graders

	Agree	Neutral	Disagree
Peer collaboration			
I enjoy learning with my classmates			
I can clearly let others know my ideas in a tea			
Problem-solving			
When my toys are broken, I will try to think of ways to get them fixed			
When my toys are broken, I will look for tools that can fix them			

	Agree	Neutral	Disagree
Engineering design skills			
I enjoy turning papers, cardboards or cans into handicrafts or funny ideas.			
I am a productive student in making handicrafts in the class			
Career orientation			
I would like to become an inventor in the future			
I look forward to more engineering and science courses			

The learning attitude survey for fourth and sixth graders

	Strongly agree	Agree	Neutral	Disagree	Strongly disaagree
Peer collaboration					
I enjoy learning with my classmates					
I respect opinions from others and show my appreciation					
I can clearly let others know my ideas in a team					
Problem-solving					
When my toys are broken, I will try to figure out the cause of the damage					
When my toys are broken, I will try to think of ways to get them fixed					
When my toys are broken, I will look for tools to fix the problem					
Critical thinking					
I choose the follow the majority rule in a team					
I follow whatever the teacher teaches me without a doubt					
My classmates who spend more time on leisure show low achievement in learning					
Career orientation					
I would like to become an inventor in the future					
I think attending more engineering and science courses will greatly benefit my future academic study					
I look forward to more engineering and science courses					

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