Chapter 7
Innovative STEM Curriculum to Enhance Students' Engineering Design Skills and Attitudes Towards STEM

Meng-Fei Cheng and Yu-Heng Lo

Abstract Although STEM education has been advocated internationally, the integration of interdisciplinary learning into STEM education and the gender disparity in the STEM field are challenging. Our research team in Taiwan developed a female-friendly and innovative STEM curriculum with flat (rather than bulky) speakers to enhance male and female students' creativity in developing new technology and to foster their interdisciplinary thinking. Participating year 10 students were encouraged in the 3-hour course to integrate science knowledge into their engineering design processes in order to better develop, evaluate, and revise their technology products. In this study, we examined this STEM curriculum to show the progression of male and female students' engineering designs and their attitudes towards STEM. Through the systematic guidance of the STEM curriculum, students' engineering designs improved, regardless of gender. There were no significant differences between male and female students' performance in engineering design in each stage of the STEM curriculum, However, in terms of the improvement in engineering design ability, female students did not improve whereas their male counterparts did in some activities. Participating in the STEM curriculum developed by this study increased the positive attitudes of both male and female students towards STEM and STEM learning. It also reduced the attitude gap between the two genders seen before the course in the technology dimension. The study findings can contribute to the development of better ways of integrating interdisciplinary learning and teaching and enhancing male and female students' engineering designs and attitudes towards STEM.

Keywords Physics · Engineering design · Attitudes towards STEM · Curriculum design · Assessment of STEM learning

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Introduction

Science, technology, engineering, and mathematics (STEM) education has been advocated internationally in order to enhance technology competition at a national level (Freeman et al., 2019). In order to enhance competition in the technology industry in Taiwan, it is also essential to urgently improve the country's industrial structure and expand high-tech industry with cutting-edge innovations. Accordingly, STEM education should be promoted in order to integrate science into engineering learning, enhance technological innovation, and integrate engineering design into the science curriculum to enhance students' interest in learning about science and engineering.

Furthermore, as a vital issue in interdisciplinary teaching in current science education in Taiwan, STEM education must emphasize the priorities of the current curriculum guidelines for K-12 science education issued by the Ministry of Education of Taiwan (2018a). These include the implementation of a literacy-oriented curriculum and the development of learning goals that integrate the STEM subjects into the science and technology curriculum so that students can practice the creative processes of conceptualization and resolution of scientific and technological problems in daily life.

Moreover, in STEM fields, women are generally underrepresented globally (Ceci & Williams, 2007; Freeman et al., 2019), including Taiwan (Ministry of Education of Taiwan, 2019). Therefore, this study aimed to design an innovative female-friendly STEM curriculum that emphasizes interdisciplinary teaching not only to integrate different disciplines and to cultivate inquiry and problem-solving abilities, but also to enhance male and female abilities and interest in learning about STEM subjects. The curriculum designed in this study can be used as a demonstration model and guideline for teachers designing their own STEM courses, thereby facilitating better implementation and promotion of STEM education.

STEM Education

In many countries around the world, the proportion of higher education students who pursue education in engineering and science is limited; this has resulted in a workforce shortage (De Vries, 2018; Han et al., 2015; Raju & Clayson, 2010). For this reason, education scholars from various countries have dedicated themselves to promoting the implementation of STEM curricula in primary and secondary schools to improve students' interest in pursuing STEM-related careers.

Students in Taiwan are more inclined to engage with STEM-related industries than students in other countries. According to statistics published by the Ministry of Education of Taiwan in 2018, Taiwan had the highest proportion of students enrolled in science- and technology-related departments in universities at 40.9% (Ministry of Education of Taiwan, 2018b, see Table 7.1). Consequently, there is no shortage of

Table 7.1 The ratio of university student enrolment by discipline (Ministry of Education of Taiwan, 2018b)

Academic year	Total	Humanities	(%)	Social studies	(%)	Science and technology	(%)
2008	1,006,102	166,953	16.6	380,479	37.8	458,670	45.6
2009	1,010,952	171,656	17.0	384,707	38.1	454,589	45.0
2010	1,021,636	176,439	17.3	393,310	38.5	451,887	44.2
2011	1,032,985	183,051	17.7	403,079	39.0	446,855	43.3
2012	1,038,041	187,950	18.1	412,806	39.8	437,285	42.1
2013	1,035,534	192,151	18.6	416,629	40.2	426,754	41.2
2014	1,037,062	195,292	18.8	421,439	40.6	420,331	40.5
2015	1,035,218	197,237	19.1	423,450	40.9	414,531	40.0
2016	1,015,398	195,602	19.3	414,604	40.8	405,192	39.9
2017	985,927	198,532	20.1	389,494	39.5	397,901	40.4
2018	961,905	194,857	20.3	373,716	38.9	393,332	40.9

science and technology talent in Taiwan. However, we are concerned with improving the quality of this talent in order to promote competition in the technology industry. Hence, there is a need for STEM education in Taiwan that fosters school students who are more capable of innovative, problem-solving, and interdisciplinary thinking, and to enhance the core literacy (systematic thinking and problem solving) promoted by the Ministry of Education of Taiwan in the current education standards for all citizens.

Integrated STEM education often involves teaching science and mathematics subject content through problems related to technology and engineering, thereby facilitating better connections between these different subjects, as well as a more interactive learning process for students (Honey et al., 2014). In other words, integrated STEM education is an interdisciplinary teaching approach. However, integrating multiple subjects into teaching in a meaningful way poses a significant challenge, given that the content and teaching methods of the four contributing subject areas are not always entirely correlated (Bell, 2016; de Vries, 2018; Kertil & Gurel, 2016; Margot & Kettler, 2019; Radloff & Guzey, 2016). In order to address this issue, we designed a teaching method based on the 6E (Engage, Explore, Explain, Engineer, Enrich, Evaluate) teaching model proposed by the International Technology and Engineering Educators Association (Burke, 2014), with the goal of better integrating the different STEM subjects and the practice of scientific and technological inquiry. In our STEM curriculum, we integrated knowledge of scientific models into students' engineering processes and utilized mathematics to collect and analyse data. This supported students into explicitly drawing on scientific and mathematical knowledge and reasoning to better resolve a technological and engineering problem.

STEM Education and Girls

In STEM occupations and departments, males outnumber females, especially in European and American countries (Stephenson et al., 2021). In the hope of addressing this gender inequality, there have been many studies exploring women's interest, confidence, and career choices in STEM fields in recent years (Blackburn, 2017). According to the Department of Statistics of the Ministry of Education of Taiwan, 75% of university students who graduated from STEM-related departments in Taiwan in 2019 were male (Ministry of Education of Taiwan, 2019), demonstrating that the gender gap also needs to be addressed in Taiwan. Understanding how women think and feel about STEM fields and the potential causes of gender inequality will enable researchers to design a female-friendly curriculum that will encourage both men and women to actively participate. In other words, understanding female perspectives can inform the design of interventions to enhance female interest and confidence in STEM fields, thereby alleviating gender inequality in STEM fields in Taiwan. Furthermore, increasing the proportion of women in STEM industries is expected to create emerging and innovative industrial ecosystems through women's ability to think creatively and critically (Gurski & Hammrich, 2017).

First, this paper discusses examples of STEM courses designed to enhance female attitudes towards STEM in Taiwan. Lou and colleagues (2011) implemented a solar energy vehicle-themed STEM course with the goal of participating in the competition of a solar energy vehicle with optimal speed and stability. This course included 40 students in a girls' senior high school, and interviews were conducted afterward to ascertain students' attitudes towards and thoughts on STEM. The students generally responded that the STEM course made them realize the importance of STEM-related knowledge and the fun and practicality of applying it to solve problems. The course also assisted students in exploring future career opportunities and establishing positive attitudes towards STEM learning.

It can be argued on the basis of these research findings that the STEM course positively affected female students' attitudes towards STEM. Nevertheless, in that study, all the research subjects were female, meaning that the difference in attitudes between the two genders before and after the STEM course could not be determined. Therefore, in our study, we developed a female-friendly STEM curriculum for students of both genders. A student attitude survey about STEM and the learning environment was conducted before and after the curriculum in order to explore differences in attitudes between the two genders and whether the STEM course was effective in terms of reducing differences between genders.

Other research has investigated reasons why female learning attitudes and career choices towards STEM differ from those of males. According to studies in the United States (Lindberg et al., 2010; Robinson & Lubienski, 2011), there is no significant difference between boys' and girls' performance in terms of spatial intelligence. However, men's performance gradually outpaces women's after formal education in elementary and secondary school, and this gender difference becomes more pronounced as their educational attainment increases. Wai et al. (2012) also revealed that male students generally perform better than their female counterparts in mathematics and science subjects in elementary school. However, if we look at the performance of each gender in science and the liberal arts, rather than comparing the academic ability of males and females, female performance in science is as good as liberal arts, and their performance in science is not significantly different from their performance in the liberal arts; males, however, perform better in the sciences than in the liberal arts (Wang et al., 2013). Valla and Ceci (2014) attribute the lower proportion of women in STEM careers to the fact that women excel in a wide range of disciplines and therefore invest more time in different fields than do men, who tend to excel in the sciences, resulting in men who focus on the sciences outperforming women in terms of both mathematical and science ability and representation in STEM careers.

On the other hand, research has pointed out that female confidence in mathematics and science is generally lower than that of males at the beginning of the school year, not because of poor academic performance but because females often attribute setbacks in STEM fields to an innate lack of ability rather than to a lack of effort (Chen & Moons, 2015; Ellis et al., 2016; LaCosse et al., 2016). This attribution affects girls' tendency to avoid difficulties when faced with problems in related fields (Dweck, 2007). However, the underlying gender bias that causes females to think this way is related to society's perception that females are generally better at liberal arts than at science. Therefore, it is considered common for females to underperform in the sciences (Jackson et al., 2014).

In terms of career choices, women are generally more inclined towards and interested in careers related to "people" and are therefore less willing to enter STEM fields than are men, who are generally more interested in "things" (Su et al., 2009). Moreover, when choosing their profession, women will often consider whether they can contribute to society and help others; that is, women generally prefer altruism to the pursuit of utilitarianism (Diekman et al., 2015, 2017). As for the choice of work environment, women are generally more likely to choose a workplace in which they can work with others, and are generally more likely to choose a career in which they feel a greater sense of belonging. Thus, women are more likely to choose careers such as teaching and nursing rather than STEM-related careers, which are considered less interactive (Su & Rounds, 2015). A lower sense of belonging and the unfriendly environment can apply to STEM-related classrooms and workplaces: the term "chilly climate," coined by Seaton (2011), refers to the fact that women in STEM-related careers and classes must face gender discrimination, prejudice, and differential treatment. In other words, women may not be treated equally or fairly in this environment, which can be a critical reason for women's reluctance to enter STEM fields.

Finally, gender stereotypes and sexism are among the most significant factors influencing women's choice to enter STEM fields or careers (Moss-Racusin et al., 2015; Ryan, 2014). Although gender discrimination is generally less prevalent than in the past, it is still strongly in evidence, especially in STEM-related fields, where women are exclusively the victims (Jackson et al., 2014). As mentioned above, women tend to attribute their failure or poor performance in science to a lack of ability rather than to a lack of effort. This attribution stems from the common perception in society that when men do not perform well in STEM subjects, they do not try hard enough, whereas it is common for women not to do well in the same subjects (Tiedemann, 2000). Moreover, women who are adept at science are more likely to defy public expectations, which makes women more reluctant to choose STEM-related disciplines and industries because of their fear of going against social expectations (Cheryan et al., 2017; Jones et al., 2013).

Given the various findings presented above, increasing the proportion of women in STEM fields is a significant challenge. Fortunately, many studies have found that science courses with more open-ended discussion in high school can increase girls' willingness to choose STEM fields (Morgan et al., 2013; Redmond-Sanogo et al., 2016). Therefore, it is expected that the proportion of women in STEM fields will increase if the relevant STEM courses can be designed to attract greater female participation.

Dancstep and Sindorf (2018) compiled and identified four pedagogical strategies to develop female-friendly courses through reviewing prior research: enabling social interaction and collaboration, creating a low-pressure setting, providing meaningful connections, and representing females and their interests.

First, enabling social interaction and collaboration recognizes that women generally prefer to cooperate with others to accomplish goals or interact with others during course activities. Conversely, women generally exhibit negative emotions if course activities are competitive. Second, creating a low-pressure setting requires that the course difficulty is moderate. Making the course too difficult will lead to science anxiety and render students less interested and less confident. Setting the course difficulty to moderate, and using open-ended questions and topics will help to reduce the pressure girls feel in the classroom. Third, providing meaningful connections involves ensuring that the topics and products explored in the course are meaningful; that is, course content should relate to solving social problems, improving quality of life, or solving environmental issues. These types of meaningful connections can encourage girls to become more engaged with and interested in the course. Lastly, with regard to girls and their interests, females are generally more interested than males in aesthetics and creativity. Thus, if the course includes these elements, the interest of girls may also increase.

The four strategies for girl-friendly courses align with the findings presented earlier that identified barriers and opportunities for engaging girls in STEM education and future STEM careers. That the course should be cooperative rather than competitive aligns with findings that women generally tend to choose careers that involve getting along with others and working together. That the course should be conducted in a low-stress environment reflects the fact that when girls face science-related setbacks, they often blame their ability rather than a lack of effort, resulting in their unwillingness to accept challenges and setbacks and in their giving up. Thus, setting the appropriate level of difficulty can help increase girls' interest in STEM programmes. The subject of the course should also benefit society and reflect the altruism of women, who tend to prioritize helping others when choosing their career.

Although boys generally out-perform girls in mathematics and science, girls' critical thinking, teamwork, and problem-solving abilities are better than those of boys (Gurski & Hammrich, 2017). Developing STEM courses for women that suit their interests is important to increase their willingness to engage in related fields (Su et al., 2009; Wang et al., 2015) and to balance the gender gap in STEM fields. This will enable Taiwan to leverage different kinds of expertise to solve social problems, as well as creative ideas to develop innovative industries.

The Context of This Study

The STEM curriculum in this study was designed on the basis of the characteristics of female-friendly curriculum design introduced above. First, the focus of the curriculum was the creation of the innovative flat speakers. The goal was to improve traditional stereo speakers, which are bulky and take up much space. The innovative flat speakers would be able to be integrated with artwork, such as oil paintings, and with everyday items such as pillows, helmets, and car surround-sound systems. This project would ensure that the curriculum helps solve problems, improves people's quality of life, and involves artistic elements, in which girls are generally interested, thus increasing their engagement.

Second, this STEM curriculum requires students to work collaboratively in groups. Individuals would discuss their own flat speaker designs with their team members, observe the advantages of each other's designs, and collaborate on the final design of the flat speaker. The team would then work together to produce the speaker, discuss its limitations, and consider methods to improve it. Students would discover that they needed mutual assistance and collaboration to complete the course activity; this is in line with the characteristics of course activities that girls tend to prefer, that is, involving interaction with others rather than competition.

Third, assessment of students' learning progress involves an open-ended engineering structure drawing. The assessment requires students to design and draw a series of structures of a flat speaker that can emit the maximum volume. Students are required to identify the required components, describe the scientific principles of how the components work, and explain why their flat speaker can emit the loudest sound. In order to verify whether their structural drawings meet the desired outcome, students discuss their designs with their peers, analyse the drawings using scientific knowledge, actually make the speaker, and then further revise it on the basis of their findings. In other words, the activity is arranged in such a way that students evaluate their structural drawings and make modifications rather than simply have their output judged as right or wrong. This was intended to reduce the pressure felt by girls to be 'successful' in the learning environment.

Fourth, the enrichment stage of this course involved applying what is learned in the classroom to designing a holiday card with a flat speaker that can emit the maximum volume, allowing students to reflect on and apply what they have learned and to add creative and artistic elements in the creation of holiday cards. The activity combined applicability, aesthetic creativity, and open-ended assessment to reduce pressure in the learning environment and therefore to appeal to girls, increase their engagement, and potentially increase their long-term interest in STEM fields.

Accordingly, this study describes a STEM curriculum designed to integrate interdisciplinary knowledge with consideration of female-friendly topics and teaching strategies in order to enhance both male and female students' engineering design abilities and their learning attitudes. The purpose of the study was to investigate whether this experimental STEM curriculum could enhance male and female students' engineering design abilities and their attitudes towards science, technology, engineering, and the learning environment.

Methodology

This study was aimed at exploring the effects of a STEM curriculum on the engineering design and affective attitudes of male and female students. The curriculum was designed on the basis of the 6E framework. During the curriculum, we conducted a series of assessments to evaluate students' progress in their ability to design engineering products. We also assessed their attitudes before and after the curriculum to shed light on changes in their perceptions of the STEM field and STEM courses.

Participants

The research participants were grade 10 students from seven high schools in central Taiwan. A total of 54 students, including 30 males and 24 females, participated in the study. The participants were recruited to the course through voluntary sign-ups, which they were informed about through an announcement from their schools. This STEM curriculum was run outside of school hours, and the students were all in one class despite attending different schools. Therefore, the participants showed considerable interest in physics, and all studied topics that included electromagnetism and the relationship between electricity and magnetism in middle school.

Learning Activities

The study monitored whether the participants demonstrated improvements in their abilities in engineering design through learning activities in a STEM curriculum. We chose the design of a new and emerging technology—flat speakers—as the focus for the course, and the project involved the application of electromagnetism. The course was designed using the 6E model proposed by Burke (2014). During the 3-hour course (Activities 1~3 took 1 hour; Activities 4~5 took 1 hour; Activities 6~7 took 1 hour), the participants studied physics concepts, designed and modified flat speaker model designs, and built actual models after observing stereo speakers, designing prototypes, conducting laboratory experiments, and discussing their ideas.

Relevant learning was included for each of the underpinning STEM domains. For science, we included theories related to the generation of sound, the form of sound transmitted through conducting wires, and models of electromagnetic induction. For technology, we covered the construction of a flat speaker that features maximized volume and application in daily life, such as pillows, paintings, or cards. For engineering, we delved into creating structure diagrams, constructing flat speakers, and modifying and improving the products. The difference between engineering and technology was that engineering emphasized the process of design, construction, and modification of the products, while technology focused on the products and applications. For mathematics, topics such as measuring decibels and transforming data into graphs were covered. The activities in each phase of the 6E curriculum are listed in Table 7.2. In activities 1, 2, 3, and 7, students drew and recorded their flat speaker structure diagrams individually. However, in activities 4 and 6, students were asked to discuss their ideas with their group members and to create a flat speaker, and then further examined the factors affecting speaker volume in their own groups.

Instruments

Evaluating the impact of the course was divided into two stages: the assessment of the students' engineering design, and the administration of a questionnaire regarding the students' attitudes towards STEM.

Assessment of Students' Engineering Designs. To keep track of the students' learning progress during the engineering design, they were asked to record their structural drawings of volume-maximized flat speakers in their learning journals in four activities: brainstorming on the structure of flat speakers (activity 1), disassembling a real stereo speaker (activity 2), explaining the magnetic effect of an electric current (activity 3), and designing a holiday card with flat speakers playing sound at maximum volume (activity 7). Analysis of these drawings enabled the researchers to investigate changes in the students' design skills as they progressed through the course.

Survey of Students' Attitudes towards STEM and the Learning Environment. The students completed an attitudinal survey before and after the STEM course to investigate any changes in their attitudes with regard to technology, engineering, science, and the STEM learning environment. Since the mathematics part in this STEM course only included drawing graphs of functions, the dimension of mathematics was not included in the attitude survey. Accordingly, survey questions were selected to serve this aim. The 19-question survey, which was adapted from Han and Carpenter (2014) and Unfried et al. (2015), required the participants to rate items on a 5-point Likert scale (*strongly agree*, *agree*, *neutral*, *disagree*, and *strongly disagree*). Each item included a description of a particular attitude, and each participant was instructed to select only one response informed by their own situation. The reliability of each scale ranged from 0.71 to 0.90. Example attitudinal survey items for the engineering dimension are given in Table 7.3.

Table 7.2 Flat speaker design using the 6E teaching model

Teaching activities	6E Model stages	Tasks
Activity 1: Brainstorming about the structure of the flat speaker	Engage	1. A video about innovative technologies involving flat speakers was played to arouse the students' learning motivation 2. Students independently pondered how to create a flat speaker that can produce maximum volume and then visualized and recorded their ideas via structure diagrams
Activity 2: Disassembling a real stereo speaker	Explore	1. The students were asked to reverse engineer real stereo speakers and observe their internal structure 2. Once again, the students were instructed to think about how to create a flat speaker that could produce the maximum volume, and to visualize their ideas in the form of structural drawings
Activity 3: Explaining the magnetic effect of an electric current	Explain	1. The teacher explained the principle of sound generation from vibration, the magnetic effect of an electric current, and the application of these principles to the design of a stereo speaker 2. Students thought about how to create a flat speaker that could produce the maximum volume and visualized their ideas in the form of structure diagrams on the basis of what they had learned about stereo speakers

(continued)

Table 7.2 (continued)

Teaching activities	6E Model stages	Tasks
Activity 4: Creating a flat speaker	Engineer and evaluate	1. Group members shared their individual flat speaker designs and discussed how to construct their speakers on the grounds of the engineering model of a speaker and scientific models of sound and electromagnetic force 2. Limited materials were provided to enable the teams to construct flat speakers on their own 3. Group members examined whether the finished products could operate successfully and evaluated the volume of their flat speakers 4. Each group presented the difficulties and findings that arose during the flat speaker production in front of the entire class, with reflections on the engineering model of a speaker and scientific models underpinning the operation of a speaker
Activity 5: Explaining the factors that affect speaker volume	Explain	1. The teacher led the class in a discussion of the factors and principles that relate to speaker volume, with the scientific model of electromagnetic force as a reference
Activity 6: Discussing and testing the factors affecting speaker volume through experimentation	Engineer and evaluate	1. Each group discussed how they could improve the volume of the flat speakers they had developed in Activity 4 by examining the factors that affect the strength of an electromagnet, with the scientific model of electromagnetic force as a reference 2. During the group discussion, group members designed an experiment using several flat speakers with different designs to explore the relationship between the modified variables and volume 3. The entire class investigated the differences in speaker volume using various variables and compared their findings with predictions they had made based on the scientific model of electromagnetic force

(continued)

Table 7.2 (continued)

Teaching activities	6E Model stages	Tasks
Activity 7: Designing a holiday card with flat speakers playing sound at maximum volume	Enrich and evaluate	1. The students were asked to use what they had learned in the course, along with their creative ideas, to design a flat speaker holiday card that could emit maximum volume 2. During the design process, the students were asked to evaluate whether their design products could operate successfully at maximum volume in accordance with what they had learned about the engineering model of a speaker and the scientific models relating to how a speaker works

Table 7.3 Attitudinal survey for the engineering dimension

Thanks to engineering, there will be greater opportunities for future generations
I like to imagine creating new products
If I learn engineering, then I can improve things that people use every day
I am interested in what makes machines work
Knowing how to use math and science together will allow me to invent useful things

Data Analysis

Assessment of Students' Engineering Designs. The students' engineering designs were classified into four levels (low to high) on the basis of the structure diagrams that they drew in their learning journals (Table 7.4).

Table 7.4 Classification of students' engineering designs into four levels

Level	Description
Level 1	The design does not reflect the major sound-producing components of the speaker and includes only unrelated components or duplicates the appearance of the original
Level 2	The design is informed by the correct selection of components and includes an appropriate description of the sound-producing structure and relative placements
Level 3	The design reflects and illustrates the principles and mechanisms related to how components interact with one another and comprises appropriate explanations
Level 4	The design not only features the components required and their mechanisms but also reflects how components in their diagrams can maximize speaker volume. These enhanced components proposed by students may include the number or position of the magnets or the shape or diameter of the coil

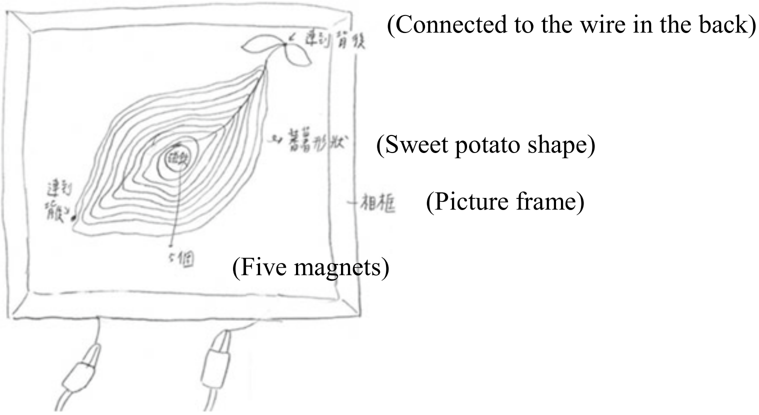

Fig. 7.1 An example of a level 4 flat speaker design

A Level 4 example of an engineering design from one of the students is shown in Fig. 7.1. In this design, the student indicated the main components and mechanisms and reflected on how the components can make the speaker as loud as possible. The coil and five magnets are the main components of the speaker. The principle underlying the design of the coil is that, through the audio source, the coil will produce a magnetic effect of an electric current. The reason for making the speaker as loud as possible is that the circular coils comprise many loops and the inner loop is close to the magnet. The design of the five magnets is based on the principle that magnets will enable the current-carrying coils to vibrate and produce sound waves. The student's experiments show that the speaker will produce the maximum sound with five magnets.

Due to the ordinal scale of the assessment and the small sample size, we performed Mann–Whitney U tests on the four activity stages to compare the levels achieved by the students and to examine how the males and females differed in terms of engineering design abilities before, during, and after the STEM class. We then carried out Wilcoxon signed-rank tests to compare the progression of the male and female students' engineering designs at different stages of the course, and to explore whether the different activities impacted male and female students' design development in a similar or different manner.

Evaluation of Student Attitudes. To investigate changes in the male and female students' attitudes towards technology, engineering, and science as well as classroom performance, we analysed the responses to the attitudinal surveys using Wilcoxon signed-rank tests for the pre- and post-course surveys. We also conducted Mann–Whitney U tests on the students' attitudes in the pre- and post-course surveys to identify whether there were gender disparities.

Results

Gender Gap in Engineering Design

As can be seen from Table 7.5, there were no significant differences between male and female students' performance in engineering design in each stage of the STEM curriculum, and their performance gradually but significantly improved throughout the different stages of the course. Thus, through the systematic guidance of the STEM curriculum, students' abilities to develop, evaluate, and revise their engineering designs improved, regardless of gender.

Through this curriculum, male students' abilities in engineering design progressed from the lower mean score of 1.36 to the higher mean score of 3.61, and female students' abilities in engineering design progressed from the lower mean score of 1.27 to the higher mean score of 3.64 (Table 7.5). Wilcoxon signed-rank tests showed significant improvement in both male students' abilities ($z = -4.50$, $p < 0.001$) with a large effect size ($r = 0.60$) and female students' abilities ($z = -4.20$, $p < 0.001$) with a large effect size ($r = 0.63$) in engineering design between activity 1 and activity 7.

In Table 7.5, the Mann–Whitney U tests indicated that there was no significant difference in the engineering design performance of the two genders in each activity. The continuous increase in the mean scores of male and female students' engineering design from Activity 1 to Activity 7 revealed that the engineering design abilities of both genders gradually and continuously improved through the course.

To examine whether male and female students' performance in engineering design progressed differently across the different activities, a Wilcoxon signed-rank test was conducted between different activities (Table 7.6).

According to Table 7.6, Activities 1 to 2 had an impact for both genders (z for males $= -3.70$, $p < 0.01$, $r = 0.49$; z for females $= -4.14$, $p < 0.01$, $r = 0.62$) with a medium and a large effect size respectively, but Activities 2 to 3 and 3 to 7 had an impact only for males. Therefore, Activity 2 is the most impactful activity among all activities, additional impacts being cumulative throughout the course. The

Table 7.5 Mann–whitney U Tests for the differences between male and female performance of engineering design in different activities

Variable	Groups	*N*	*M*	*SD*	*U*	*z*	*p*	*r*
Activity 1	Male	28	1.36	0.87	299.00	−0.252	0.801	0.04
	Female	22	1.27	0.55				
Activity 2	Male	28	2.71	0.98	254.00	−1.113	0.266	0.16
	Female	22	3.00	0.76				
Activity 3	Male	28	3.21	0.79	307.00	−0.021	0.983	0.00
	Female	22	3.23	0.75				
Activity 7	Male	28	3.61	0.74	301.50	−0.170	0.865	0.02
	Female	22	3.64	0.73				

Table 7.6 Wilcoxon signed-rank tests of the male and female students' performance of engineering design in different activities

Stages between the activities	Gender	*N*	*M*	*z*	*p*	*r*
Activity 1 to Activity 2	Male	28	1.36	−3.70***	0	0.49
	Female	22	1.73	−4.14***	0	0.62
Activity 2 to Activity 3	Male	28	0.5	−2.25*	0.025	0.3
	Female	22	0.23	−1.18	0.236	0.18
Activity 3 to Activity 7	Male	28	0.39	−2.31*	0.021	0.31
	Female	22	0.41	−1.83	0.067	0.27
Activity 1 to Activity 7	Male	28	2.25	−4.50***	0	0.6
	Female	22	2.36	−4.20***	0	0.63

Note * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

assessment in Activity 2 asked students to revise their original design drawing of a flat speaker after they had disassembled the actual speakers. The assessment in Activity 3 required students to revise their drawing of a flat speaker after they had discussed and clarified the scientific principles underlying the workings of a stereo speaker. Next, in Activities 4 to 6, students constructed their flat speakers and discussed the factors related to speaker volume based on the scientific model of electromagnetic force. Then, they selected and tested the factors that might affect the speaker volume. The assessment in Activity 7 required students to reflect on and employ what they had learned about the engineering model of a speaker and the scientific principles of the workings of a speaker and, taking the model of electromagnetic force as their reference, to create a flat speaker holiday card that could emit the maximum volume.

Hence, Activity 2 (disassembling a real stereo speaker) enabled male students' engineering design to progress from average level 1.36–2.71 and female students' engineering design to progress from average level 1.27–3.00, as shown in Table 7.5. Both female and male students' engineering designs made significant progress from around Level 1 to around Level 3. It appears that Activity 2 (disassembling a real stereo speaker) not only enabled students to start considering the essential sound-producing components of the flat speaker but also encouraged them to start associating their design with relevant scientific models through observation and analysis of the structure of the stereo speaker.

Gender Gaps in Attitude Towards STEM and STEM Learning Environments

In this study, a Wilcoxon signed-rank test was conducted on four major dimensions for mean male and female responses to the attitudinal survey. The results for the male students are shown in Table 7.7, and the results for the female students are shown in Table 7.8.

Table 7.7 Mean scores and wilcoxon signed-rank tests for male students' responses to the attitudinal survey before and after the course

Variable	Pre-test		Post-test		*z*	*p*	*r*
	M	*SD*	*M*	*SD*			
Technology	4.34	0.51	4.54	0.46	−3.16**	0.002	0.42
Engineering	4.28	0.54	4.58	0.51	−3.91***	0.000	0.52
Science	4.14	0.54	4.50	0.49	−4.12***	0.000	0.55
Classroom environment	3.99	0.78	4.54	0.66	−3.35**	0.001	0.45

Note ** $p < 0.01$; *** $p < 0.001$

Table 7.8 Mean scores and wilcoxon signed-rank tests for female students' responses to the attitudinal survey before and after the course

Variable	Pre-test		Post-test		*z*	*p*	*r*
	M	*SD*	*M*	*SD*			
Technology	4.05	0.42	4.42	0.40	−4.02***	0.000	0.61
Engineering	4.35	0.40	4.66	0.40	−3.38**	0.001	0.51
Science	4.05	0.39	4.38	0.52	−2.98**	0.003	0.45
Classroom environment	4.07	0.65	4.77	0.44	−3.41**	0.001	0.51

Note ** $p < 0.01$; *** $p < 0.001$

Tables 7.7 and 7.8 show that the results indicated that the post-course scores of the four major dimensions are significantly higher than the pre-course scores for both genders with the effect sizes between the medium and large ranges. The results therefore indicate that participating in the STEM curriculum developed by this study increased the positive attitudes of both male and female students towards STEM and STEM learning. Although one of the objectives of the course was to develop a female-friendly course, the attitude for male students also improved significantly over the course.

Moreover, this study analysed the responses to the attitudinal surveys before (Table 7.9) and after (Table 7.10) the course for both genders, and conducted a Mann–Whitney U Test for the four major dimensions to compare the differences in male and female students' attitudes towards each dimension.

In the attitudinal survey before the STEM course, male students only had a significantly more positive attitude than female students in relation to the technology dimension (see Table 7.9, $z = -2.31$, $p < 0.05$, $r = 0.33$) with a medium effect size. However, there were no statistically significant differences between males and females after the course (Table 7.10, $z = -1.32$ $p > 0.05$). Tables 7.7 and 7.8 suggest that the STEM course improved the positive attitudes for male and female students (male students' technology dimension in Table 7.7, $z = -3.16$, $p < 0.01$; female students' technology dimension in Table 7.8, $z = -4.02$, $p < 0.001$). Therefore, the

Table 7.9 Mann–whitney U test analysis of the attitudinal survey for the male and female groups before participating in the STEM curriculum

Variable	Groups	*M*	*SD*	*U*	*z*	*p*	*r*
Technology	Male	4.34	0.51	311.50	−2.31*	0.021	0.33
	Female	4.05	0.42				
Engineering	Male	4.28	0.54	449.50	−0.323	0.742	0.05
	Female	4.35	0.40				
Science	Male	4.14	0.54	423.50	−0.70	0.482	0.09
	Female	4.05	0.39				
Classroom performance	Male	3.99	0.78	336.50	−0.15	0.878	0.02
	Female	4.07	0.65				

Note * $p < 0.05$

Table 7.10 Mann–whitney U test analysis of the attitudinal survey for the male and female groups after participating in the STEM curriculum

Variable	Groups	*M*	*SD*	*U*	*z*	*p*	*r*
Technology	Male	4.54	0.46	381.00	−1.32	0.186	0.19
	Female	4.42	0.40				
Engineering	Male	4.58	0.51	451.50	−0.31	0.757	0.04
	Female	4.66	0.40				
Science	Male	4.50	0.49	401.50	−1.03	0.305	0.15
	Female	4.38	0.52				
Classroom performance	Male	4.54	0.66	266.50	−1.55	0.120	0.21
	Female	4.77	0.44				

STEM course not only significantly increased the positive attitudes of both genders in the technology dimension, it also reduced the attitude gap between the two genders seen before the course in the technology dimension.

Discussion

This experimental STEM curriculum emphasizes the teaching methods of continuously guiding students to consider the engineering models of a stereo speaker and the scientific models of sound and electromagnetic force to develop, evaluate, and revise their designs of an innovative flat speaker. This teaching strategy was found to significantly help enhance the engineering designs of both male and female students. The learning process included thinking about the structure of a flat speaker from the students' own experience, disassembling an existing stereo speaker, and using scientific principles first to design a flat speaker and then to revise and depict the design of the speaker on a holiday card. There was no significant difference between the two genders in terms of the quality of the engineering designs.

However, in terms of the improvement in engineering design ability, female students did not improve whereas their male counterparts did, between activities 3 and 7. In these activities, students were encouraged to integrate scientific models in their engineering designs. A possible explanation is that the female students may have already incorporated the scientific principles in their original engineering design, once they had done the reverse engineering of the product. For example, a study by Lou et al. (2011) observed that females have an advantage of integrating engineering and science. Hence, females' abilities in this area are worthy of future research in relation to designing and implementing STEM curricula.

In addition, the study investigated gender differences in attitudes towards STEM. In the attitudinal survey before the course, male students' attitudes in technology were significantly more positive than those of female students. There was no significant difference between the two genders in the science, engineering, and learning environment dimensions. This is consistent with the results of a previous study by American scholars on differences in attitudes of the two genders towards STEM subjects (Chen & Moons, 2015; LaCosse et al., 2016). However, after they participated in the STEM course described in this chapter, the attitudes of male and female students had no significant difference in any of these four dimensions. Additionally, the attitudes of both genders were significantly more positive in all four dimensions. Taken together, the STEM curriculum appeared to effectively reduce the gender gap in female and male attitudes towards technology.

Although many previous studies have investigated the differences in attitudes between males and females in relation to STEM, and have suggested design directions for female-friendly courses (e.g., Dancstep & Sindorf, 2018), few have proposed complete STEM courses and detailed activities that demonstrably address the gap in attitudes between genders. This study proposed detailed STEM course content and teaching methods that reduced the gender gap in relation to students' attitudes towards technology, namely, a gender-friendly STEM course.

In the past, the content of 'female-friendly courses' centred on the activities of women's daily lives, such as kitchen science, hoping to attract female participation. In contrast, the theme of this STEM curriculum was flat speakers, which emphasized the practical application of emerging technologies. This theme was not chosen based on gender stereotypes. However, the course design drew on Dancstep and Sindorf's (2018) strategies for female-friendly courses: (1) enable social interaction and collaboration, (2) create a low-pressure setting, (3) provide a meaningful application to solve daily life issues or improve life quality, and (4) include aesthetic and creative elements. Our course demonstrated a successful application of these strategies in the creation of a STEM course. The resulting course successfully enhanced not only male but also female students' attitudes and engineering design ability.

In summary, this research showed that the design and implementation of a STEM curriculum with gender-friendly and integrated cross-disciplinary learning not only enhanced both male and female students' engineering designs and attitude towards

STEM but also reduced the gender gap between male and female students' STEM learning.

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