Using an iSTEAM project-based learning model for technology senior high school students: Design, development, and evaluation

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Abstract

The purposes of this study were to integrate imagination and STEAM education to construct a special topic course on wearable devices for pets for technology senior high school students studying electronic science; to explore the impacts of the learning process on students' imagination, STEAM competences and satisfaction with learning effectiveness; and to investigate the integration of imagination into STEAM education. This study adopted the design research method and took 40 students in the third year of a special topic course in electronic science at a technology senior high school as the research subjects. The students were randomly divided into 8 groups, and teaching activities were carried out for 18 weeks. This study used questionnaire and documentary analysis methods to carry out peer evaluation, pretests, posttests and student self-report surveys to collect qualitative and quantitative data for statistical analysis and cross-validation. In this study, a new integration model of imagination and STEAM is proposed. The design research method was employed to plan the iSTEAM course and design special topic activities about real-life issues so that the degree of integration of imagination into the STEAM special topic course and the quality of the students' work were moderately positively correlated and highly positively correlated, respectively, with students' application of their learning from various aspects of iSTEAM, which can significantly enhance their imagination, STEAM competences, and satisfaction with their learning effectiveness. The iSTEAM teaching model can help engineering educators develop and evaluate iSTEAM courses and learning activities and provides new contributions to and research directions for STEAM education.

Keywords Imagination · STEAM · Project-based learning · Education reform · Design research method

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Introduction

In 1989, the U.S. began emphasizing STEM in its educational reform, advocating for interdisciplinary, integrated education that connects disciplines with practical skills (Lou et al. 2011a, b). STEAM is an interdisciplinary course that incorporates art (art and design thinking) into STEM and aims to improve students' critical thinking skills and creativity. Based on mathematics and science, it is a discovery-oriented discipline concerned with solving practical problems with engineering or design methods, exploring the reestablishment of art education, and encouraging students to find creative solutions (Phelps et al. 2018; Maeda 2013). Art adds a new dimension to STEM learning and inspires more young people to devote themselves to the fields of science, technology, engineering, and mathematics (Ozkan and Topsakal 2019). Many scholars have pointed out that there is a significant correlation between college students who have completed STEM-related courses before enrollment and their choice to continue in engineering-related majors (Hynes et al. 2016; Miller et al. 2020). Therefore, the educational orientation of STEAM learning is conducive to the precollege engineering education and interdisciplinary and integrated course learning of technology senior high school students (Gettings 2016), which is of great importance for development and research.

In engineering education, effort is made to furnish students with skills, knowledge, imagination, creativity, and, especially, imaginative thinking, all of which plays a key role in breaking new ground in the process of economic globalization (Lin et al. 2014; Pantidos 2017). Imagination is the foundation of creativity, and constructive imagination can expand knowledge and help people address complex problems in an effective manner (Hsu et al. 2014). Moreover, it can convert existing knowledge and experience into new knowledge or discoveries and promote the flexible application of knowledge in daily life (Collins and Stevenson 2004). In terms of promoting students' exploration of and reflection on past, present, and future societies, cultural backgrounds, and experiences, this study expects to show the effects and benefits of strengthening students' imagination in precollege engineering education.

Multiple scholars have argued that STEAM can accelerate imaginative thinking (Eisner and Powell 2002). In addition, making good use of imagination can integrate educational resources as well as develop learning strategies, stimulate learning potential, deepen understanding, reduce the learning load, and improve mental simulation and imagination among students (Beaty et al. 2018). However, Perignat and Katz-Buonincontro (2019) reviewed 44 articles on STEAM education from 2007 to 2018 and found that the STEAM concept had many definitions and lacked learning outcomes in terms of imagination, creativity, problem solving, and art education. It can be seen that integrating imagination education and design thinking into STEAM education has the value of deepening exploration and promoting precollege engineering education (Tsai 2016; Kant et al. 2018).

In her trend report in 2013, Mary Meeker said that the personal computer industry entered a third cycle—the era of wearable mobile devices—after two main cycles, those of the smartphone and tablet (Carmody 2013), which shows that the wearable device is the direction in which new technologies are being developed. In today's society, many people own a pet, and if wearable devices are designed for pets, pet owners will be able to interact with their pets at any time and at any place, check their physical condition, and track their activities. The study of wearable devices designed for pets is an interesting topic that has real-life applications. Unlike with other special topic STEAM courses, students learning about such wearable devices must imagine the real needs and feelings of pet owners

and pets by observing the interactions between them. The main features of design thinking about wearable devices for pets include a rich imagination- and art-development space, the integration of engineering education, the provision of opportunities for students to conduct hands-on work, and interdisciplinary and integrated exploration in science, technology, engineering, art, and mathematics to cultivate students' high-level abilities, such as critical thinking, systematic thinking, creative thinking, and imagination (Quigley et al. 2017). In addition, such learning can enhance students' cognition, attitudes, and interest in engineering education and thus cultivate talent through both theory and practice. Finally, the high-quality results of its implementation can lead to patent applications or commercialization, providing great business opportunities and promotional value.

Therefore, based on the importance of imagination education and design thinking in the field of engineering education (Wright and Wrigley 2019), this study strengthens the integration of imagination and STEM education, develops a new iSTEAM course using design thinking, takes the students of a technology senior high school studying electronic science as the research object, and takes the design of wearable devices for pets as the outcome of emerging science and technology engineering design activities in order to conduct practical research to verify the effectiveness of the learning mode. This study has five objectives as follows:

1. To develop an iSTEAM course for technology senior high school students studying electronic science;
2. To explore the impacts of the iSTEAM course on technology senior high school students' imagination;
3. To probe examine the impacts of the iSTEAM course on technology senior high school students' STEAM competences;
4. To explore technology senior high school students' satisfaction with the learning effectiveness of the iSTEAM course;
5. To explore the integration of imagination and STEAM in the iSTEAM course.

Literature review

Definition of and research on STEAM

STEM education is an educational method that combines the knowledge, skills, and ideas of science, technology, engineering, and mathematics (Baran et al. 2016; Blom and Bogaers 2020). Through the practice of engineering design and the application of scientific technologies, STEM courses provide students with opportunities to combine theory with practice. Moreover, it focuses on the systematic thinking of scientific exploration and mathematics analysis in practice, which guides students to integrate STEM knowledge with practical applications and develops their high-level thinking abilities (Herschbach 2011; Lou et al. 2011a, b). Moreover, it can improve students' learning attitudes and behavioral intentions regarding STEM knowledge (Huang and Huang 2007).

STEAM=STEM+A (art and design thinking), which indicates that art and design thinking is incorporated into an interdisciplinary course that includes science, technology, engineering, and mathematics (Lu and Ma 2019; Maeda 2013). The art component makes everything else meaningful. It encourages students to take risks and be tolerant towards different opinions; inspires comfortable creation and design; differs from mathematics, which

underlines right and wrong; and can simplify complicated data in science (Michaud 2014). Hence, combining art with technological education can make learning more flexible, trigger innovation, and lead to the establishment of an inquiry-based and discovery-oriented discipline. Based on mathematics and science, the course in this study is about solving practical problems with engineering or design methods and encouraging students to find creative solutions, thus equipping the students with required competences such as critical thinking, creative thinking, problem-solving, and creativity (Zalaznick 2015).

In STEAM education, students are encouraged to think creatively and critically from the perspective of aesthetics, engage in creative interactions with teachers and peers, analyze themes from diverse angles, explain and evaluate their work, understand how to express their ideas, and learn from feedback to acquire more skills (Ozkan and Topsakal 2019). Therefore, the STEAM practice course requires students to integrate and use knowledge from different fields and give play to their imagination and creativity. In addition, it emphasizes knowledge exchange and sharing among peers and aims to furnish students with basic integrated STEAM knowledge and strong problem-solving abilities so that they will be able to develop better solutions in the face of a fast-changing future (Harris and de Bruin 2018; Hickey-Moody et al. 2019).

Bequette and Bequette (2012) found that a STEAM-based interdisciplinary, multifaceted imaginative situation could lead students from familiar and ordinary situations to broad situations full of previously untapped imagination where they can probe into complex social issues and develop more holistic and realistic viewpoints through dialogue. Hence, this study incorporates imagination into STEAM education to provide students with opportunities to develop diversified imagination and to learn and think with interdisciplinary knowledge. With a focus on students and the intention of effectively improving students' thinking abilities and tapping their imagination potential in their personal creations, this study adopts open-ended statements and elaborates on students' imaginative and creative solutions for real-world problems.

Model and application of imagination education

Imagination is a process of picture evolution in the minds of human beings and is closely related to images and emotions; in other words, it is a process based on emotion and existing image memories, where old and new images are recombined through perception to create a new image (Collins and Stevenson 2004). The study described in "Course and teaching model of future imagination" by Lin (2011) led students to consider "a valuable future". In addition to imparting interdisciplinary knowledge to students, it sparked their imagination, creative thinking, and critical thinking skills and motivated them to make a blueprint and an action plan for the future using the following steps: "considering the future", "imaging the future", "choosing the future", and "creating the future". Wang et al. (2010) put forth the imagination training model of "IDEAL" in which (1) "Initiation" means utilizing existing experience to trigger new ideas and possibilities; (2) "Development" leads students to develop new ideas out of initial ideas using their imagination; (3) "Alternative" implies that if students always stay in the stage of association and think from only one perspective, they find it difficult to achieve their ends; and (4) "Links" focuses on "connection" and compares various solutions to select the best one to develop more new ideas.

Ho et al. (2013) divided the imagination process in science into three stages, namely, "initiation", "dynamic adjustment", and "virtual practice". The details of the imagination

process in science are as follows (Wang et al. 2014): (1) the initiation stage—this stage underlines the number of ideas students generate when trying to solve problems and encourages them to express their ideas; it is also called “brainstorming”; (2) the dynamic adjustment stage—this stage focuses on selecting a new idea from among a large number of ideas to solve problems and inspires students to identify the relationships among ideas, combine the ideas into a new idea, and assess that idea’s feasibility; and (3) the virtual implementation stage—this stage emphasizes what is done in the previous two stages and motivates students to create a prototype for something based on the new idea; it inspires students to express their ideas or make design drawings and encourages them to put their ideas into action.

According to the literature review, the imagination process comprises generation, initiation, and transformation stages; therefore, the first stage of the imagination process in this study is defined by “exploring” or “enriching mental materials” and is a stage in which data and experience are used to generate cognitive experiences. The second stage is the mental process of imagination development, which consists of “brainstorming”, “association”, “transformation”, and “connection”. In this stage, effort is made to extend thinking and continually develop, dismantle, reconstruct, and connect ideas. Then, convergent thinking is adopted to gradually combine ideas into a meaningful creation element. For the last step, various media, such as language, pictures, sounds, and models, are utilized to translate the outcomes of imagination into concrete objects and images, which are described as “explicitness” or “concrete characteristics” in this study.

The necessity of integrating imagination into STEAM education

The NGSS report emphasized the importance of creativity and imagination in science and expressed the belief that scientific knowledge is the result of human efforts, imagination, and creativity (Pantidos 2017). De Cruz and De Smedt (2010) believed that imagination is essential when individuals are creating new work. Ho et al. (2013) proposed that scientific imagination is a type of purposeful imagination, which is a mental activity that applies scientific principles and connects to daily life experiences to generate novel ideas. Egan (2005) called on teachers to integrate abundant imagination into their teaching methods and practice developing students’ imagination. In this way, students can be guided to focus their mental energy on interesting and important issues and improve their intrinsic learning motivation in order to focus on and immerse themselves in course activities, which helps them strengthen their knowledge absorption and form a positive attitude towards repeating such experiences and actively seeking knowledge (Glass and Wilson 2016). In summary, imagination is complementary to the purpose of STEAM education in cultivating students’ integrated knowledge and problem-solving ability (Allina 2018).

Einstein once said, “It takes imagination to ask new questions, to open up new possibilities, and to look at old problems from new perspectives; imagination is the driving force of scientific progress” (Policastro and Gardner 1999). Gardner (2011) proposed the multiple intelligence theory, which stressed that students need a broad basis of thinking to understand the changing world and that they need to master the various methods of thinking, as well as the ability to imagine and simulate solutions. Clearly, imagination has become an important concept that cannot be ignored in the field of education. It is worth noting that “imagination” is an innate ability in all humans; however, as people grow older, they gradually lose the motivation to explore and imagine, and they fail to make good use of their imagination to activate their mental thinking. Therefore, this study requires a clear

conceptual system as a precursor to effectively integrating imagination into the STEAM teaching methods, developing good curriculum, and guiding students to succeed in learning (Costantino 2018). The course in this study was divided into six STEAM stages, each including opening questions and connections between past and current tasks. Moreover, there was a bilateral feedback relationship between the stages that could be supplemented or modified at any time. The stages were designed to guide students to imagine, integrate, and apply STEAM knowledge.

Research design

Based on the research purpose and literature review, this study developed an iSTEAM course for technology senior high school students studying electronic science. The duration of the course was 18 weeks, with three periods each week, and included some group learning activities, such as the creative design competition for wearable devices for pets (pet device design competition) and 6 iSTEAM tasks. The design research method was adopted to explore the effects of the iSTEAM course on technology senior high school students' STEAM competences and their learning effectiveness in the special topic course.

Research process

This study was carried out with the design research method shown in Fig. 1, including the four stages of “preparation”, “implementation”, “evaluation”, and “popularization” (Brown 1992; Hira and Hynes 2019). The process between the “preparation” and “implementation” stages could be repeated. Each stage's details are as follows:

Preparation: establishing a theoretical foundation and generating a design prototype

After confirming the actual teaching problems in the case school, it was found that the most severe problem was inadequate student learning intentions. After a discussion with the instructors and the students at the case school, further analysis offered a clear picture of the nature of the problem, which was defined as stemming from boring course content and students' addiction to mobile phone games. According to the research objectives of this study, academic papers about imagination, STEAM, and related topics were analyzed and discussed to establish a theoretical foundation for the iSTEAM teaching model for this study. Moreover, this study planned out how to distribute tasks among the instructors and researchers and how to collect relevant data in the later stages.

Implementation: testing the design of the research

The research objectives of this study were to develop an iSTEAM course and construct a teaching model for it; the teaching materials, tools, and strategies necessary for the actual teaching were planned and used to adjust the content and activities in the original course. As shown in Table 1, this stage included three teaching actions—integrating the curricular outlines of electrical machinery and electronic science, designing a basic and application-oriented iSTEAM course, and planning competitions for wearable devices for pets. Various methods, such as direct observation, questionnaires, investigation, and testing, were adopted to collect the necessary data in an organized manner, and the written data included

Fig. 1 Design Research Process

learning feedback forms, pretest and posttest questionnaires, records of group discussions, special topic reports, and group interview records.

Evaluation: analyzing the data to determine teaching effectiveness and gradually optimize the design

Effort was invested in the trial and demonstration of actual teaching activities. After the trial stage, when various data and evidence were collected, the qualitative and quantitative data were analyzed to verify the hypotheses and improve the actual teaching activities, and a feedback mechanism was adopted. All these tasks were repeated until the difficulties or problems were resolved.

Popularization: spreading the research achievements of the study in the educational market

The research team participated in data analysis and design optimization, made a complete report on the research results, and promoted the research achievements to the educational community. In doing so, this research team hoped to help teachers, parents, students, and administrative workers utilize the research results to improve the teaching and learning processes. The effects of the popularization were evaluated, revealing that attention must

Table 1 Modification-oriented comparison for the implementation of the course

Special topic course		iSTEAM course	
Week	Content	Week	Content
1–2	1. Concepts of special topic creation; 2. Collection and reading of academic papers; 3. Group planning (the suggestions for the implementation of the pretest were transferred from Week 12 to Week 1)		
3–4	1. Language framework and Arduino framework; 2. C Language framework; 3. Application of resources of online platforms; 4. Program ideation and reconstruction		
5–8	<i>Unit 1: Application of LEDs and Sensing Switches</i> 1. Analysis of LED features and types, and creation of the LED control program 2. Photosensitive resistor and a tilt-sensing control program		
9–11	<i>Mid-term special topic report: sharpen practical integration skills</i> Finish combining the photosensitive resistor and tilt-sensing features and designing the software program to control the devices; program the actual electric circuit device to test its functions	9–11	<i>Unit 2: Application of LEDs, Temperature, and Humidity Sensing</i> 1. Analyze the features and types of temperature- and humidity-sensing modules; design and create the control program for the modules 2. Apply the features of the temperature and humidity sensing modules and the RGB LED light bar; design and create a control program for the temperature- and humidity-sensing modules
12–14	<i>Unit 2: Application of LEDs and Temperature and Humidity Sensing</i> 1. Analyze the features and types of temperature- and humidity-sensing modules; design and create a control program for the modules 2. Apply the features of the temperature- and humidity-sensing modules and the RGB LED light bar; design and create a control program for the temperature- and humidity-sensing modules	12–18	<i>Unit 3: Special topic: iSTEAM wearable device for pets</i> 1. Introduction to the pretest and competition 2. Initiation of the special topic competition: designing a wearable device for pets 3. 6 iSTEAM tasks Task 1: Application of wearable device for pets Task 2: Application of the concept of iSTEAM Task 3: Creative design blueprint of the iSTEAM wearable device for pets Task 4: Records of the actual use of wearable device functions Task 5: Completion of the written report Task 6: Release of the competition results 4. Posttest
15–17	<i>Final special topic report: improve practical integration skills</i> Finish combining the photosensitive resistor and RGB LED light bar and designing the software program to control the devices; program the actual electric circuit for the device to test its functions		
18	Finish the final special topic report		

be paid to the special features of the research data, and caution is needed when applying them to other contexts.

Research subjects

The research objects were 40 students in a project-development course in electronic science who were in their third year at a technology senior high school in Taiwan. The students were randomly divided into 8 groups and participated in the teaching design study for 18 weeks. The theme of the wearable device for pets was chosen for use with students studying electronic science because the students already had considerable electronics-related background knowledge; therefore, they were more able to focus on iSTEAM learning components than ordinary students would be, which saved time understanding electronic parts and effectively reduced the students' learning load. Moreover, the introduction of iSTEAM learning can enhance engineering students' cognition, attitudes, and interest in imagination and art learning and help promote STEAM engineering education.

Research method and tools

This study adopted the design research method, the questionnaire method, and the document analysis method to develop an iSTEAM course for technology senior high school students. The authors designed a scale for the application of imagination and STEAM learning in student work (peer evaluation), a STEAM competence test (consisting of a pretest and posttest), and questionnaire on satisfaction with learning effectiveness (student self-report) were adopted to conduct a survey using peer evaluation, pretest and posttest, student self-report, and other methods to explore technology senior high school students' imagination and STEAM competences and the learning effectiveness of the special topic course and to understand the integration of imagination and STEAM in this iSTEAM course. Descriptions of these research methods are as follows:

Design research method

The design research method was put forth by Ann Brown in 1992 to improve practices, optimize designs, and develop theories, and the method focuses on testing theory-based designs in an actual learning environment and offering feedback to designers to help with the modification and development of theories (Brown 1992). In long-term, repetitive formative research (Collins et al. 2004), the design research method can be applied in four major activities in educational research: (1) clarifying theoretical issues about the nature of learning in an actual situation; (2) exploring learning-related phenomena in the real world rather than in a controlled experimental context; (3) conducting widely applicable educational research using targeted assessments, and (4) obtaining research findings through formative assessments. In addition, this method has four major features (Hsu et al. 2012): (1) theory-based designs for testing the feasibility of theories or proposing prototype theories; (2) a detailed record of the research process and interactions in the system; (3) the valuable repetition of modifications, thus revealing the modification process; and (4) systematic analysis that helps in exploring multilayered interactions.

Therefore, the design research method, which is based on imagination and STEAM research, was adopted in this study. After designing the teaching process, this study conducted a systematic analysis of the research data regarding actual teaching to connect

teaching designs with educational theories, thus developing an iSTEAM teaching model that can be applied in actual teaching. With a view to enhancing the learning motivation of technology senior high school students studying electronic science, this study determined the following competence indices of the iSTEAM course: (1) special topic creation, (2) the expertise and qualifications required by the electronic profession, (3) the ability to make wearable devices for pets, and (4) the ability to investigate and analyze the accessories of the pet module. Moreover, other activities, such as the 6 iSTEAM tasks and the pet device design competition, were integrated with the teaching activities of the special topic course, and the design research method was used for the special topic teaching research to further strengthen the students' practical ability and improve their imaginative thinking and capability to integrate knowledge and solve problems.

Questionnaire method

The questionnaire method is a method that researchers adopt to carry out a planned survey among selected subjects by using a standardized questionnaire, which is a tool designed to collect data (Pathak 2008). The researchers in this study created a STEAM competence test and a questionnaire on satisfaction with learning effectiveness for technology senior high school students and invited two experts to evaluate the representativeness of the results by examining the research topic dimensions in the questionnaire in order to test the measure's content validity. A questionnaire survey was conducted to explore the impacts of the iSTEAM course on technology senior high school students' ability to apply imagination and STEAM learning in their work, their STEAM competences, and the learning effectiveness of the special topic course.

Exploratory factor analysis (EFA)

Purposive sampling was adopted to select 103 subjects for the trial test for the validity of the above two questionnaires. After the questionnaires were retrieved for project analysis and inappropriate items were removed, principal component analysis was combined with Varimax for orthogonal rotation to extract the factors. The scale for the application of imagination and STEAM learning in student work includes 24 items in two categories, namely, the appearance modeling of imagination (3 items), functional imagination (3 items) and value imagination (3 items) in the category of the application of imagination and science (3 items), technology (3 items), engineering (3 items), art (3 items), and mathematics (3 items) in the category of the application of STEAM learning. The factor loadings of each dimension were 0.82~0.90, 0.78~0.89, 0.83~0.91, 0.77~0.87, 0.85~0.93, 0.86~0.92, 0.79~0.87, and 0.88~0.90, respectively, and their Cronbach's α values were 0.88, 0.84, 0.89, 0.85, 0.89, 0.91, 0.85, and 0.90, respectively, with a medium-high level of reliability.

STEAM competence testing was carried out using test items divided into five categories (S, T, E, A, and M), as shown in Table 2. The teachers designed the test item library according to the focuses of the special topic course, and six items were randomly selected for each category. The factor loadings of the dimensions of the STEAM competence test were "0.67~0.84", "0.76~0.84", "0.78~0.90", "0.81~0.91", and "0.69~0.85", respectively, and their Cronbach's α values were "0.92", "0.89", "0.91", "0.90", and "0.91", respectively. These results indicate that the STEAM competence test had a medium-high level of reliability; thus, it was unnecessary to remove any items to increase the Cronbach's

Table 2 Model items in the STEAM Competence Test

Dimension	Model items
Science	Which of the following determines the color of an LED light? (1) Material element (2) Current (3) Voltage (4) LED volume (5) All of the above
Technology	Which of the following is not a common output unit component in the experiment? (1) Photosensitive resistor (2) Motor; (3) LCD (4) Relay (5) None of the above
Engineering	The device that converts direct current into alternating current is: (1) The rectifier (2) The voltage doubler (3) The wave filter (4) The current transformer (5) All of the above
Art	Which of the following is not a type of color contrast? (1) Complementary color contrast (2) Simultaneous contrast (3) Brightness-darkness contrast (4) Fading contrast (5) All of the above
Mathematics	If two 1.5-voltage batteries are in a series connection, the combined voltage will be: (1) 1.5 V (2) 3 V (3) 4.5 V (4) 6 V (5) None of the above

α . Moreover, the questionnaire on satisfaction with learning effectiveness included imagination stimulation (5 items), special topic creation ability (6 items), and STEAM competences (5 items), and the factor loadings of these three dimensions were 0.76~0.82, 0.69~0.84, and 0.81~0.90, and Cronbach's α were 0.92, 0.91, and 0.94, respectively, which shows that the questionnaire has a medium-high level of reliability.

Documentary analysis

Documentary analysis refers to the process of collecting and analyzing relevant documents to draw a conclusion (Hsieh 2009). In this study, triangulation was employed to increase the reliability of the research data. Creative work based on the cooperative learning of the students and special topic reports were used to analyze and evaluate the students' performance. Furthermore, learning process feedback on the 6 iSTEAM tasks from the learning groups was utilized to review the teaching and learning and analyze the students' performance in each stage.

Planning the iSTEAM course

Based on a literature review and courses on electrical machinery and electronic science, this study designed a special topic course and added the interdisciplinary element of an iSTEAM teaching framework. With a focus on wearable devices for pets, the course aimed to strengthen students' ability to practice and integrate knowledge from different courses and emphasized the connections with their real-life experiences. The content of the iSTEAM course was dominated by the 6 iSTEAM tasks, competition for the creative design of wearable devices for pets, and the meaning of iSTEAM knowledge, which are introduced as follows:

6 iSTEAM tasks

Details regarding the 6 iSTEAM tasks in this study are shown in Table 3. By including the practices from engineering and design, this course required the students to integrate scientific technologies with scientific exploration and mathematical analysis to develop creative solutions in the problem-solving process to enhance their STEAM competences. The

Table 3 Meaning of the 6 iSTEAM Tasks

Stage	Definition
(1) Exploration	Explore the existing environment and cultural background and accumulate knowledge on wearable devices for pets
(2) Brainstorming	Set the starting point and goal of imagination according to existing experience and explore knowledge on wearable devices for pets
(3) Association	Expand the imagination, analyze the structure of wearable devices for pets, and determine the circuit
(4) Transformation	Set a new starting point or think in reverse starting from the goal; assemble and experiment with the components of wearable devices for pets
(5) Connection	Converge and connect all ideas and add a new dimension into them, in order to define the theme and the contextual content; begin to design wearable devices for pets
(6) Explicitness	Put imagination into action and create wearable devices for pets; test the devices and make modifications

implementation of the interdisciplinary teaching framework of iSTEAM helped the students pay more attention to the application of their creative designs for a wearable device for pets. In addition, group learning, discussion, sharing, and interactions were combined to enable all of the students to express their views, strengthen their intention to participate in learning interactions, and give full play to their talents (Blom and Bogaers 2020; Lou et al. 2011a, b).

Pet device design competition

This study took the educational meaning of iSTEAM and the curricular outline of the special topic course for students studying electrical machinery and electronic science as the axis of the course development. A pet device design competition was held, and the 6 iSTEAM tasks model was adopted for teaching so that the students could fully understand the applications for wearable devices and designs for pet accessories. The curricular outline and the competence indices are shown in Table 4.

According to the curricular plan, the competition started with an activity orientation and pretesting in Week 12, and a number of experts and scholars were invited to give special topic lectures to sharpen the students' practical skills related to iSTEAM work to create wearable devices for pets. Moreover, the 6 iSTEAM tasks model was implemented from Week 13 to Week 16 to guide the students in designing and creating a wearable device for pets, including testing its functions, writing a report, and detailing their achievements. In the last step, the posttest questionnaire was conducted for statistical analysis.

Definition of iSTEAM knowledge of Pet-oriented wearable devices

This study involved designing an 18-week student-centered course and determining the iSTEAM knowledge required for the students. Details regarding the imagination (i), science (S), technology (T), engineering (E), art (A), and mathematics (M) components included in the pet device design competition are shown in Table 5. The devices were made using the design procedure, and their functions were tested in the application stage. In addition, a special topic design competition for wearable devices for pets was held. During

Table 4 Content of the iSTEAM Course

Week	Stage	Theme	Content	Competence index	iSTEAM
12	Orientation	meeting on the special topic creation	Meeting to introduce the competition		
13	Exploration	Primary exploration of the iSTEAM project about wearable devices for pets Task 1: Conceptual drawing of the device	Imagining a special wearable device that meets pets' needs and is comfortable Possible problems and difficulties in the creation process Drawing up draft designs and provide written instructions for the design ideas	Competence indices of the special topic creation Ability to make wearable device for pets Pet module accessories	i, S, T, E
14	Brainstorming	Task 2: Application of the concept of iSTEAM	Ideation and reconstruction of the language program iSTEAM concept Exterior design Combination of the Arduino framework and circuits Integration of technological and artistic elements	Expertise and qualifications required by electronics professions Ability to make wearable devices for pets	i, S, T, E, A, M
15	Association	Task 3: Creative design blueprint of iSTEAM-developed wearable devices for pets	The combination of LEDs and optical sensing and of tilt sensing and the temperature and humidity module WiFi transmission Completion of the creative design blueprint of the iSTEAM-developed wearable device for pets Completion of a design diagram for the functional device and a detailed written description	Expertise and qualifications required by electronics professions Ability to make wearable devices for pets	i, S, T, E, A, M

Table 4 (continued)

Week	Stage	Theme	Content	Competence index	iSTEAM
16–17	Transformation Connection	Task 4: Record of the functions of the wearable device in reality Task 5: Completion of the written report	Accessory design and circuit setting of the wearable device for pets Display of the actual work; testing of the device and the recording	Expertise and qualifications required by electronics professions Ability to make wearable devices for pets Pet module accessories	i, S, T, E, A, M
18	Explicitness	Task 6: Release of the results of the special topic design competition	Report on the results of the special topic creation	Competence indices of the special topic creation	i, S, T, E, A, M

Table 5 Definition of iSTEAM Knowledge in the Pet Device Design Competition

iSTEAM scope	Definition
Imagination	<p>Consider how to make a special wearable device that meets pets' needs and is comfortable</p> <p>Consider how to apply the theories and skills in the course to make the expected device</p> <p>Imagine how a simple device can gradually evolve into one that allows people to conduct online observations and measurements</p> <p>Imagine how to enable people to obtain information about the health of their pets in a more convenient manner</p>
Science	<p>LED illumination and the color principle</p> <p>Application of scientific knowledge-based wireless communication technologies, such as WiFi, Bluetooth, and the 4G network</p> <p>Application of the natural sciences, including external conditions, such as temperature, humidity, pressure, and brightness</p> <p>Optical wave illumination intensity and the principle of digital analog A/D conversion</p>
Technology	<p>LEDs, RGB LEDs, photosensitive resistor, and tilt sensor</p> <p>The wearable device designed for pets</p> <p>The combination of the built-in system and communication protocol of the Internet of Things</p> <p>The inclusion of smart control and WiFi- and cloud-based real-time monitoring</p>
Engineering	<p>Adopt the iSTEAM teaching model to guide the students through the design process</p> <p>Assemble the circuits and wires of the LEDs, photosensitive resistor, and tilt sensor; write programming codes</p> <p>Undertake function testing, detect and solve problems, and optimize the device</p> <p>Make the wearable device for pets and integrate the necessary materials</p> <p>Solder, test, and modify the circuit panel</p>
Art	<p>Integrate the circuit components with aesthetic ideas and add artistic features to the exterior</p> <p>Understand that different people have different aesthetic views, and different opinions can lead to many creative ideas</p> <p>Learn to appreciate, be tolerant of, and respect the ideas of different people</p> <p>Focus on the visual effects of the wearable device for pets to accumulate aesthetic design experience and develop a positive attitude and the ability to appraise aesthetic value</p>
Mathematics	<p>Calculate the LED brightness, flash time, and RGB values</p> <p>Calculate the designs of the programming loop, delay, and drive clock</p> <p>Measure the current and voltage</p> <p>Measure pet collars, the weight of different devices, and the size of clothes</p>

the course, to strengthen their teamwork and ability to distribute tasks and solve problems, the students were required to engage in cooperative learning in groups.

Research results and discussion

This study aimed to determine the effects of the iSTEAM course on technology senior high school students' imagination, STEAM competences, and learning effectiveness in the special topic course. Details regarding the pretest and posttest on the students' STEAM competences, the questionnaire regarding their satisfaction with learning effectiveness, and the analysis and discussion of the students' learning process are as follows:

Statistical analysis and discussion of the application of imagination and STEAM in work

The creative work of 8 groups of students was evaluated by peer evaluation in this study. After 5 students were removed from the test sample, the 35 remaining students participated in the peer evaluation of creative work, and a total of 280 scored results were collected. The scoring items comprised two categories, the application of imagination and the application of STEAM, and these can be described as follows.

Application of imagination in work

Students were invited to evaluate the application of imagination in each group's work using 9 items spread across the 3 dimensions of the appearance modeling of imagination, functional imagination, and value imagination, and the statistical analysis results are shown in Table 6. The mean of each item was between 3.24 and 3.63. A t-test analysis of a single sample with a test value of 3 showed significant positive differences, which are explained as follows.

In terms of the appearance modeling of imagination, Item 1 (work with an exquisite, special, and distinctive design and shape) received the highest score, with a mean of 3.55 (SD=0.92) and a t value of 10.05, followed by Item 2 (work with unprecedented design innovation), with a mean of 3.55 (SD=0.88) and a t value of 10.50.

In terms of functional imagination, Item 6 received the highest score, with a mean of 3.59 (SD=0.87) and a t value of 11.30, followed by Item 5, with a mean of 3.50 (SD=0.87) and a t value of 9.60.

In terms of value imagination, Item 8 received the highest score, with a mean of 3.63 (SD=0.91) and a t value of 11.48, followed by Item 9, with a mean of 3.56 (SD=0.86) and a t value of 10.97.

In summary, most of the students positively perceived the application of imagination in their peers' work. They thought that the work was exquisite, special in terms of its appearance modeling and different from other wearable devices; that the functional diversity and practicality of the work were worthy of promotion and development; and that the work was aesthetically pleasing and innovative in terms of value design, thus making them all very suitable for practical use with pets.

Application of STEAM in student work

Students were invited to evaluate the application of STEAM learning in each group's work using 15 items spread across the 5 dimensions of science, technology, engineering, art, and mathematics, and the statistical analysis results are shown in Table 6. The mean of each item was between 3.31 and 3.81. The t-test analysis of a single sample with a test value of 3 showed significant positive differences, which are explained as follows.

In terms of the application of science learning, Item 11 received the highest score, with a mean of 3.43 (SD=0.89) and a t value of 7.97, followed by Item 10, with a mean of 3.41 (SD=0.91) and a t value of 7.60.

Table 6 Analysis of the application of imagination and STEAM learning in students' work

Dimension	Item	N = 280		
		Mean	Standard deviation	t
Appearance Modeling of Imagination	1. Work with an exquisite, special, and distinctive design and shape	3.55	0.92	10.05***
	2. Work with unprecedented design innovation	3.55	0.88	10.50***
	3. Work with a novel design and shapes different from those of other wearable devices	3.37	0.97	6.36***
Functional Imagination	4. Work that applied very diverse and special parts	3.44	0.83	8.95***
	5. Work with diverse and practical functions	3.50	0.87	9.60***
	6. Work worthy of promotion and development	3.59	0.87	11.30***
Value Imagination	7. Work with an aesthetically pleasing and innovative design	3.24	0.95	4.15***
	8. Work that is very suitable for practical use with pets	3.63	0.91	11.48***
	9. Work with a novel design in terms of shape and color	3.56	0.86	10.97***
Science	10. Work that applied scientific knowledge of wireless communication technology	3.41	0.91	7.60***
	11. Work applied scientific principles related to sensors	3.43	0.89	7.97***
	12. Work that applied scientific principles and knowledge related to wearable devices for pets	3.31	1.00	5.23***
Technology	13. Work that applied electromechanical control technology	3.53	0.97	9.13***
	14. Work that applied intelligent control, process tools, and equipment-using technology	3.35	0.88	6.63***
	15. Work that applied the core technology of the IoT	3.46	1.01	7.68***
Engineering	16. Work that applied problem-solving abilities	3.46	0.94	8.25***
	17. Work that applied creative thinking ability in modeling the design	3.67	0.85	13.28***
	18. Work that applied structural design and blueprint drawing abilities	3.70	0.78	15.06***
Art	19. Work that applied aesthetic experiences, attitudes, and appreciation	3.61	0.90	11.46***
	20. Work that applied creative thinking in its development	3.76	0.76	16.65***
	21. Work that applied creativity and design principles	3.81	0.80	17.04***

Table 6 (continued)

Dimension	Item	N = 280		
		Mean	Standard deviation	<i>t</i>
Mathematics	22. Work that applied measurements and calculations, such as area, volume, half diameter, circumference, angle, etc.	3.63	0.88	11.99***
	23. Work that applied measurements and calculations, such as energy conversion, current, voltage, resistance, etc.	3.78	0.84	15.44***
	24. Work that applied relevant mathematical measurements and calculations	3.70	0.88	13.35***

(Verification value = 3) ****p* value = 0.00

In terms of the application of technology learning, Item 13 received the highest score, with a mean of 3.53 ($SD=0.97$) and a t value of 9.13, followed by Item 15, with a mean of 3.46 ($SD=1.01$) and a t value of 7.68.

In terms of the application of engineering learning, Item 18 received the highest score, with a mean of 3.70 ($SD=0.78$) and a t value of 15.06, followed by Item 17, with a mean of 3.67 ($SD=0.85$) and a t value of 13.28.

In terms of the application of art learning, Item 21 received the highest score, with a mean of 3.81 ($SD=0.80$) and a t value of 17.04, followed by Item 20, with a mean of 3.76 ($SD=0.76$) and a t value of 16.65.

In terms of the application of mathematics learning, Item 23 received the highest score, with a mean of 3.78 ($SD=0.84$) and a t value of 15.44, followed by Item 24, with a mean of 3.70 ($SD=0.88$) and a t value of 13.35.

In summary, most of the students positively perceived the application of STEAM learning in their peers' work (Park et al. 2016). They thought that their creative work applied scientific principles related to wearable devices for pets, such as wireless communication technology, sensors, etc., and technical skills related to electromechanical control, the Internet of Things (IoT), process tools and equipment, etc.; gave play to problem-solving and creative thinking ability in the structural and modeling designs of the work; made full use of the students' aesthetic experiences and appreciation abilities in the creation and design process; and accurately applied mathematical measurements and calculations, such as area, half diameter, circumference, current, voltage, resistance, etc.

Analysis and discussion of STEAM competences

This study adopted sample t testing analysis to explore the impacts of the iSTEAM course on technology senior high school students' STEAM competences, as shown in Table 7; the degree of freedom was 39, and the analysis results are as follows:

Table 7 Comparison of STEAM competences between the pretest and posttest

Item		Mean	Standard deviation	Mean of posttest–pre-test	Standard deviation	t	Degree of freedom	Significance (two-tailed)
Science	Pretest	1.57	0.98	−0.03	1.12	0.40	39	0.638
	Posttest	1.54	0.97					
Technology	Pretest	.72	0.89	0.61	1.32	14.73	39	0.000
	Posttest	1.33	1.06					
Engineering	Pretest	1.28	0.85	0.07	0.99	0.30	39	0.584
	Posttest	1.35	0.63					
Art	Pretest	1.37	1.04	0.26	0.98	4.21	39	0.040
	Posttest	1.63	1.03					
Mathematics	Pretest	1.91	1.05	0.77	1.15	21.46	39	0.000
	Posttest	2.60	0.75					

No remarkable increase in the students' science competence

According to the analysis results, the science competence of technology senior high school students studying electronic science in the case school was higher in the pretest (Mean = 1.57, SD = 0.98) than in the posttest (Mean = 1.54, SD = 0.97), and the *t* value was 0.40 (SD = 1.12, $p = 0.638 > 0.05$), which demonstrates that there was no significant increase in their science competence. Thus, there was no noticeable gain in the science competence of the students who took the special topic course.

According to the results, through the special course, the subjects acquired a basic understanding of fundamental scientific knowledge and principles, including LED illumination, the color principle, temperature, humidity, pressure, and brightness, after they completed the first two units: Unit 1—The Application of LEDs and Sensing Switches and Unit 2—The Application of LEDs and Temperature and Humidity Sensing. During Unit 3 of the course, Special topic: iSTEAM-developed wearable devices for pets, the student groups spent only a small proportion of time collecting scientific data and conducting the inquiry and thus failed to enhance their science competence; instead, they spent more much time on the application of technology. It could be seen in their work that the students seldom used science knowledge in the later stages of the project. This finding can inform future modifications of the special topic course used in this study.

Marked increase in the students' technology competence

According to the analysis results, the technological competence of the technology senior high school students studying electronic science in the case school was higher in the posttest (Mean = 1.33, SD = 1.06) than in the pretest (Mean = 0.72, SD = 0.89), and the *t* value was 14.73 (SD = 1.32, $p = 0.000 < 0.05$), which demonstrates a significant increase in their technology competence. In other words, there was noticeable gain in the technological competence of the students who took the special topic course.

This result shows that the subjects had great motivation and interest in applying technologies such as LEDs, photosensitive resistors, and tilt sensors in the design of their wearable device for pets after they took the special topic course. Most of the work by the subjects combined a built-in system and the communication protocol of the Internet of Things, and the changes in pet moods could be monitored by checking changes in the frequency of viewing the pet data on the Internet. This demonstrates that there was a remarkable increase in the students' technology competence.

No noticeable increase in the students' engineering competence

According to the analysis results, the engineering competence of the technology senior high school students studying electronic science in the case school was higher in the posttest (Mean = 1.35, SD = 0.63) than in the pretest (Mean = 1.28, SD = 0.85), and the *t* value was 0.30 (SD = 0.99, $p = 0.584 > 0.05$), which shows that there was no significant increase in their engineering competence. Thus, there was no noticeable gain in the engineering competence of the students who took the special topic course.

This result reveals that the subjects became accustomed to the course model after they finished the first two units, Unit 1: The Application of LEDs and Sensing Switches and Unit 2: The Application of LEDs and Temperature and Humidity Sensing. In addition, the

engineering planning and design processes were based on the students' achievements in the previous two units when the students studied Unit 3: Special topic: iSTEAM wearable devices for pets; therefore, there was no significant increase in their engineering competence. The pretest results in this study can inform future modifications of the special topic course used in this study.

Noticeable increase in the students' art competence

According to the analysis results, the art competence of the technology senior high school students studying electronic science in the case school was higher in the posttest (Mean = 1.63, SD = 1.03) than in the pretest (Mean = 1.37, SD = 1.04), and the *t* value was 4.21 (SD = 0.98, $p = 0.040 < 0.05$), which shows that there was a marked increase in their art competence after the special topic course.

This result demonstrates that the subjects spent much time and energy on the creative and aesthetic components of the device design after studying the special topic unit; for example, they added aesthetic and visual effects into the circuit components using, for example, an LED light bar, and made the finished wearable device for pets into a polished product. Moreover, they learned how to appreciate and become tolerant towards different opinions and then combine the differing aesthetic ideas from their group in creative ways. There was a significant increase in the students' experience with aesthetics, positive attitudes, and appraisal capabilities.

Remarkable increase in the students' mathematics competence

According to the analysis results, the mathematics competence of the technology senior high school students studying electronic science in the case school was greatly higher in the posttest (Mean = 2.60, SD = 0.75) than in the pretest (Mean = 1.91, SD = 1.05), and the *t* value was 21.46 (SD = 1.15, $p = 0.000 < 0.05$), which indicates a noticeable increase in mathematics competence. This shows that there was a marked increase in mathematics competence after the special topic course.

This result reveals that the subjects strengthened their ability to calculate the functional operations of the software program code design, the loop estimate, and the delay, and in to minimize the energy consumption of their devices, they designed consumption power and component resistance values that matched the circuits in their creations.

Analysis of students' satisfaction with learning effectiveness

To measure the students' learning effectiveness in the iSTEAM course, this study carried out a questionnaire survey; 40 surveys were distributed and retrieved, and a one-sample *t* test analysis, as shown in Table 8, was conducted to explore the subjects' satisfaction with learning effectiveness. The analysis results are as follows:

In terms of imagination inspiration, item 2, "It [the iSTEAM course] expanded my knowledge of the research topic", had the highest *t* value (14.42), and its score was 4.04 ($p = 0.000 < 0.05$). This was followed by item 5, "It provided a chance to demonstrate ideas and practices", which had the second highest *t* value (10.94), with a score of 3.97 ($p = 0.000 < 0.05$).

Regarding the special topic creation ability, item 8, "It strengthened my ability to collect data", had the highest *t* value (12.42), with a score of 4.03 ($p = 0.000 < 0.05$). This was

Table 8 Analysis of the students' satisfaction with learning effectiveness

Dimension	Item	Mean	Standard deviation	<i>t</i>
Imagination inspiration	1. I learned more from the iSTEAM course than from lectures	3.84	0.68	10.72***
	2. The iSTEAM course expanded my knowledge of the research topic	4.04	0.63	14.42***
	3. I gained new knowledge from the reports of others	3.93	0.83	9.77***
	4. It [the iSTEAM course] triggered my imagination	3.91	0.74	10.63***
	5. It provided a chance to demonstrate ideas and practices	3.97	0.77	10.94***
	6. The iSTEAM course was a learning approach that integrated various fields of knowledge	3.83	0.81	8.82***
Special topic creation ability	7. It strengthened my problem-solving ability	3.77	0.85	7.90***
	8. It strengthened my ability to collect data	4.03	0.72	12.42***
	9. It improved my ability to analyze data	3.95	0.80	10.20***
	10. It strengthened my ability to put theory into action	3.99	0.80	10.72***
	11. It reinforced my information capability	3.96	0.76	10.92***
	12. It enhanced my science competence	3.67	0.76	7.60***
STEAM competences	13. It strengthened my technology competence	3.81	0.83	8.45***
	14. It enhanced my engineering competence	3.75	0.76	8.56***
	15. It reinforced my art competence	4.03	0.92	9.72***
	16. It increased my mathematics competence	3.12	0.92	1.14

(Verification value = 3) *** *p* value = 0.00

followed by item 10, “It strengthened my ability to put theory into action”, which had the second highest *t* value (10.72), with a score of 3.99 ($p=0.000<0.05$).

Regarding STEAM competences, item 15, “It enhanced my art competence”, had the highest *t* value (9.72), with a score of 4.03 ($p=0.000<0.05$). This was followed by item 13, “It strengthened my technology competence”, which had the second highest *t* value (8.45), with a score of 3.81 ($p=0.000<0.05$).

According to the above analysis, most of the subjects showed satisfaction with their progress in all the dimensions, with the exception of item 16, “It increased my mathematics competence”, which had a low *t* value (1.14) and the lowest mean (3.12) and did not reach a significant level ($p=0.26>0.05$). The results of item 16 show that the students felt insignificant gains in mathematics competence because the microcontroller Arduino and the sensing components used in the practice were modularized, and these components were downloaded in the form of an open-ended functional library program, which resulted in their low-frequency of use in students’ calculations.

Analysis and discussion of the integration of imagination and STEAM education

This study integrated imagination into STEAM education to develop an iSTEAM teaching model. Therefore, this study carried out a Pearson’s product difference correlation analysis of imagination and STEAM using 280 peer evaluation results to examine the integration between them. Regarding the degree of correlation of Pearson’s product difference correlation coefficient, a result above 0.8 indicates an extremely high positive correlation, a result between 0.6 and 0.8 indicates a highly positive correlation, a result between 0.4 and 0.6 indicates a moderately positive correlation, a result between 0.2 and 0.4 indicates a low positive correlation, and a result below 0.2 indicates an extremely low positive correlation (Redmond and Griffith 2005). The Pearson’s product difference correlation analysis results, as shown in Table 9, are described as follows.

The correlation analysis results show that the correlation coefficient between imagination and STEAM was .56, which was a significant level and thus indicated a significant and moderately positive correlation between imagination and STEAM. Furthermore, this study discussed the correlations between imagination, science, technology, engineering, art, and mathematics. Imagination is moderately positively correlated with science, technology, and engineering, with correlation coefficients of .57, .52 and .49, respectively, all of which reached a significant level. This result shows that there is a significant linear relationship between imagination and STEAM, and the higher the score of imagination in students’

Table 9 Pearson correlation analysis of iSTEAM

Item	i	S	T	E	A	M	STEAM
i	1	0.57***	0.52***	0.49***	0.26***	0.18** (0.002)	0.56***
S		1	0.72***	0.52***	0.33***	0.29***	0.79***
T			1	0.55***	0.33***	0.24***	0.79***
E				1	0.51***	0.42***	0.80***
A					1	0.47***	0.68***
M						1	0.64***
STEAM							1

****p* value = 0.00

work is, the higher the evaluation score of the application of STEAM, especially in science, technology, and engineering. In other words, the result indicates that this iSTEAM course has a good integration of imagination and STEAM education (Taljaard 2016).

Comparative analysis of and discussion regarding expert scores of students' work and peer scores of iSTEAM

To explore the relationship between the quality of the students' work and their iSTEAM performance, this study invited three experts to grade the work of the 8 groups of students when their final results were published. The scoring items included 30 points spread across the three categories of appearance modeling (10 points), functionality (10 points), and value (10 points). As shown in Table 10, the average scores of the students' work ranged from 18.2 to 24. Furthermore, the iSTEAM peer scores of each group were calculated, and these ranged from 19.29 to 23.05.

This study conducted Pearson product difference correlation analysis between the expert scores of the work of the 8 student groups and the iSTEAM peer evaluation scores, and the correlation coefficient was 0.844 (p value = $0.008 < 0.01$), thus reaching a significant level and indicating a significantly high positive correlation between them. The analysis results show that the quality of the work of the 8 groups as evaluated by the three experts was highly positively correlated with the performance of the work in terms of the various aspects of iSTEAM. In other words, the better the performance of the students' work was in terms of iSTEAM concepts, the higher the quality of that work.

The performance and quality of students' work in terms of iSTEAM concept were examined and ranked by expert evaluation, as shown in Fig. 2. It is clear that the students' work in the first quadrant performed well in imagination and STEAM, and it received better rankings, including first and second place, as well. Therefore, the stronger the students' iSTEAM abilities are, the better the quality of their work is and the higher the evaluation from experts is (Sochacka et al. 2016).

Analysis and discussion of the students' learning process

During the implementation of this course, this study involved collecting records of the students' interviews and discussions as well as the students' learning lists, assignments, notes, and written reports in order to observe their discussions, participation in the activities, displays of ability, and important feedback. Moreover, qualitative text analysis was utilized to understand the students' study of the iSTEAM course. The students' learning and practice can be summarized as the following three results:

Planning a special topic competition that applied to the real world effectively strengthened the students' imagination and learning motivation

By changing the learning situation and adopting a special topic competition to be applicable in the real world, this study boosted the students' learning motivation. First, the authors planned the pet device design competition and held an orientation meeting. In addition to the theme, content, and form of the activities being introduced at the meeting, two professors were each invited to give a lecture—"iSTEAM Practice" and the "Application of Wearable Devices"—and to serve as councilors for the students, which deepened the students' understanding of the research and helped them swiftly focus on

Table 10 List of students' scores

No.	Imagination (1)	STEAM (2)	S	T	E	A	M	iSTEAM (3)=(1)+(2)	Ranking	Expert score	Place
1	9.75	9.83	8.94	9.69	9.63	10.26	10.66	19.58	7	21.00	6
2	9.72	9.57	8.80	9.20	9.63	10.40	9.83	19.29	8	18.20	8
3	9.63	10.46	8.77	8.77	11.00	11.83	11.94	20.09	6	20.00	7
4	9.65	10.68	9.51	10.14	10.83	11.83	11.09	20.33	5	24.00	3
5	11.43	11.35	11.23	10.91	11.49	11.89	11.26	22.78	2	23.30	5
6	11.15	10.64	10.57	10.23	10.86	10.97	10.57	21.79	4	24.00	3
7	11.36	11.69	11.86	11.86	11.57	11.26	11.89	23.05	1	26.40	1
8	11.11	11.56	11.51	11.91	11.69	11.06	11.63	22.67	3	25.00	2

Fig. 2 Scatter plot of students' imagination and STEAM scores

what to learn. 09S3: *“The two professors gave interesting lectures, through which we were informed of the theme of the competition and became active in asking questions.”* In this way, this study inspired the students' imagination, piqued their interest in learning, consolidated their knowledge and experience, and promoted their commitment to later-stage activities.

Regarding the target of pets and the function and form of wearable devices, most of the groups chose dogs, as many of the students had dogs at home and were familiar with the habits of dogs. The groups considered the context of their own lives and made their decisions after having a discussion. 03S1: *“Our target pet is a Chihuahua. As I have a dog at home, I suggested choosing the dog for the experiment.”* Moreover, this course included design practice, which aimed to show the students' ability to integrate their STEAM knowledge. This study required that the software program be combined with the hardware circuit. 03S3: *“We often had the problem of typing wrong program codes. So, we checked the codes together to detect and correct all of the incorrect codes.”* In addition, this study encouraged students to pay attention to the appearance and function of their work when designing wearable devices for pets, as shown in Table 11. 05S1: *“We had five members in our group, and each of us had a different idea. So, we combined the different schemes and came up with a unique product.”* Regarding the making of the circuit, it was necessary to use welding tools, basic tools, and testing equipment, and the students were expected to finish their creative design, conduct a test, and complete a functional demonstration by themselves. 01S2: *“In the early stage of the test on the wearable device for pets, the dog tried to run away and often broke the RGB light bar when it scratched an itch. So, we gave play to our creativity and put the RGB light bar into a transparent water pipe and created a dog collar (see Table 11, Example 2), thus solving the problem.”*

The competition for the creative design of wearable devices for pets offered the students a chance to put their knowledge into practice and spark their imagination. In the open environment, the students began to understand obscure STEAM concepts through group discussions. 03S2: *“Arduino is really amazing! We could design the functions with what we had learned at school. But nearly all the knowledge of Arduino is in English, so that made me read the English materials carefully.”* 01S1: *The “photosensitive resistor is based on the photoelectric effect. Adding voltage to both ends of the photosensitive resistor would generate a current. When exposed to light with an appropriate wavelength, the current will become stronger and have greater brightness, thus achieving light-electricity conversion.”*

Based on the above observations and an analysis of the feedback from students, this course, which includes iSTEAM activities that are related to the special topic, designed

Table 11 Example drawings of the device designs by the students**Example 1: Device Ideation Draft****Transformation from the Design Drawing into the Finished Product**

Device ideation: Use the ball switch to monitor tilt. Install it on the tail of a dog to monitor the tail and the frequency of tail wagging. It is connected with the LED light bar around the neck to show the mental state of the dog

Design improvement: Add an artistic design; make pet clothes and cover the circuit with the clothes, thus making the pet more attractive and not affecting the functions of the device

Analysis of the meaning of the iSTEAM knowledge in the students' device

1. Designed a wearable device combined with clothes for a pet dog [A]
2. Took the WiFi cloud control panel as the main cloud network domain; conducted bilateral transmission control through the browsing mode of a mobile phone, and replaced the ordinary Arduino circuit panel [S, T and E]
3. The overall weight was kept within a scope that was appropriate for the dog [M]
4. Adhered the wires below the clothes to achieve better visual effects [A & E]
5. Made a mood-sensing device through WiFi transmission, so that any change in the mood or health of the pet dog could be checked on a mobile phone [I, S and T]

Example 2: Device Ideation Draft**Transformation from the Design Drawing into the Finished Product**

Device ideation: The temperature and humidity monitoring function was used. The device was installed around the neck of the pet dog to monitor temperature. It was connected with the LED light bar around the neck of the pet dog to show the health of the animal

Design improvement: Added an artistic design. The device was made into an adjustable, comfortable collar for the pet dog. The circuit was covered by a belt, which made the device more attractive and would not be a burden for the animal

Table 11 (continued)

Example 2: Device Ideation Draft	Transformation from the Design Drawing into the Finished Product
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Analysis of the meaning of the iSTEAM

knowledge in the students' device

- (1) The brace style is unique and the device works as a temperature and humidity sensor [A]
- (2) The collar is adjustable so that the dog will not feel uncomfortable and the device will not fall off [E]
- (3) The WiFi cloud panel is connected with the cloud end, which facilitates observation [S, T and E]
- (4) The wires are cut to an appropriate length to be covered by the brace, which makes the device more attractive [A, E and M]
- (5) The device can monitor the dog's temperature and the dampness of its coat so that its owner can send help when the dog feels uncomfortable [i]

to solve real problems, and focused on developing the students' ability to develop designs and address problems in the real world by encouraging them to put their ideas into action and make their own wearable devices for pets (Ozkan and Topsakal 2019). In addition to enhancing the students' learning motivation and participation in activities, this work strengthened their ability to integrate the knowledge of STEAM and resolve real problems (Asghar et al. 2012; National Research Council 2012).

The 6 iSTEAM tasks helped the students solve real-world problems and finish their special topic work through cooperative learning

The special topic activity adopted the cooperative learning method of heterogeneous grouping to offer students experience with teamwork. During the activity, some students showed weak learning motivation, and some groups had to navigate disputes and complaints. In these cases, the teachers intervened to solve the problems and guide the students to achieve the mission of the activity. 07S1: "Some members were inactive in the practice, but through communication and persuasion, we managed to finish the work." As most of the students had never participated in any special topic activities, they had no idea how

the activities should progress and were often at a loss for what to do next. To solve this problem, this study included the 6 iSTEAM tasks for the iSTEAM course, which included adding ideas into a design draft through exploration and discussion, as shown in Table 11, and was intended to provide a procedure for the students to follow during their special topic work. After systematic teaching, the design draft was modified to become the basis of the students' creative design. 02S1: *"Sometimes we didn't know how to do something, but through the discussions in the 6 iSTEAM tasks, we managed to complete the tasks on time."* 08S2: *"When we got the news about the special topic work, we thought it was something easy, but we were confronted with countless difficulties in the process. After a discussion, we tried to finish the tasks in each stage, and we turned to our teachers and classmates for help."*

Regarding feedback on the 6 iSTEAM tasks, this study established six corresponding tasks: exploration, brainstorming, association, transformation, connection, and explicitness. The groups were guided to start with their conceptual drawings of the wearable devices for pets, and then, they applied their iSTEAM learning to finish the blueprints, construct their physical product, record the results of testing their creations, and share their achievements. For the students, the first necessary step was to understand the features and principles of the components of their wearable devices, and through their relevant knowledge, they were able to detect problems, stimulate hypotheses, develop solutions, create circuits, test the functions, and then complete the special topic mission as scheduled. 04S1: *"We used online information to operate Arduino. Then, we designed the circuit according to our needs. That's all we did."* 05S3: *"During the establishment of the mood-sensing circuit (see Table 11, Example 1), the program and the circuit didn't work properly after the microcontroller was soldered to the tilt sensor wire to create the circuit. We collected information about the structure of the 'ball switch', a main sensing source component of the tilt sensor on the Internet, and found that it vibrated the interior iron balls to generate a signal. In this vibration, the excessive strength caused an after-vibration, which resulted in excessive signals. This led to the incorrect assessment by the program and then caused a functional abnormality. Under the teacher's guidance, we made modifications and carried out tests and then finished our work."*

According to the above analysis, the creative design competition of the iSTEAM wearable device for pets allowed the students to put their knowledge into practice. Through cooperative learning, the group members had discussions and undertook tests, which sparked their imagination and creativity in solving problems. Based on the abovementioned quote, the cooperative learning component of the special topic course gave the students an opportunity to experience science and technology-based learning and improved their ability to process information. Moreover, it promoted their integration and application of iSTEAM knowledge and strengthened their ability to acquire integrated knowledge and address practical problems (Herschbach 2011). In addition to fulfilling the objective of interdisciplinary STEAM education, this course guided the students to detect and solve problems through knowledge integration and practice and complete their STEAM work (Long II and Davis 2017).

Incorporating iSTEAM into a special topic course can improve students' imagination and STEAM-integrated thinking

Following the curricular outlines for electrical machinery and electronic science courses, this study used iSTEAM-developed wearable devices for pets as the design project so that

the students would be able to integrate their knowledge to solve problems in the real world. The students' work was analyzed according to the definition of iSTEAM knowledge, and the analysis examined imagination, science, technology, engineering, art, and mathematics, as shown in Table 11. It can be seen in the analysis of the students' work that the students applied their iSTEAM knowledge to the design and creation of wearable devices for pets; for example, the students used concepts related to science, engineering, and technology in the circuit design. 03S1: *"It was a fresh experience for me to illuminate an LED with Arduino. It was hard for us to finish the special topic mission, and we encountered many obstacles in the process, including an incorrect circuit and program. So, we had to come up with solutions to these problems."* 02S2: *"The three primary colors (Red R, Green G, and Blue B) of the Arduino panel were used to show the variations in temperature. This brought us more creative ideas of applying technology-based products to daily life."* Likewise, the application of integrated engineering and art knowledge was examined through various aspects such as function, appearance, aesthetics, and the combination of knowledge. 04S2: *"We hoped to create a pink LED light bar with RGB because a pink collar is perfect for our dog."* 01S2: *"Through program code design, we could create an RGB LED light bar of various colors, just like a light bulb with attractive artistic effects."*

According to the above analysis, in addition to the creative designs based on imaginative processes (Herschbach 2011), the iSTEAM-developed creations of the students were mainly based on the integration of their knowledge of science, mathematics, and technology and various abilities, such as soldering circuit panels, connecting wires, and designing Arduino program controls, all of which were important factors that influenced the functions of the circuit. The process from design to creation involved many things: mathematical concepts, such as measurements and calculations; electrical elements, such as batteries, wires, and currents; the selection of components and materials; and technology knowledge, such as the use of tools. In the last step, engineering knowledge was added to the designing of the structure of the finished product, the drawing up of a draft, and the creation of the device designed by each group. Because of this experience, the students will be able to combine their imagination and STEAM-integrated thinking in the future, in which they are bound to face rapid changes that require the development of better solutions to real problems (Chung et al. 2017; Hong et al. 2016).

Comparison of the results of the qualitative and quantitative analysis

After observing the students' learning process and the subsequent analysis and summary of the written feedback from the students, the results were compared with those of the quantitative analysis, as shown in Table 12. In terms of imagination inspiration and the ability shown in creating the special topic product, both the qualitative and quantitative analysis results were consistent: most of the students felt positively about their learning effectiveness. Regarding general STEAM competences, technology and art competences were consistent, while those for science, engineering, and mathematics were partially consistent. As most of the students were participating in the special topic iSTEAM learning activity for the first time, they were curious and were willing to try new things. After the activity, most of them were satisfied with the learning effectiveness of STEAM knowledge integration, their imagination inspiration, their ability to create the special topic product, and their problem-solving ability, adding that they had mastered more diverse skills during the process (Herro and Quigley 2017; Zalaznick 2015).

Table 12 Comparison of the consistency between the qualitative and quantitative analysis results

Category		Quantitative analysis results			Quantitative analysis results	Comparison of the consistency
		Table 6	Table 9	Table 10		
Imagination		V	–	V	V	Consistent
STEAM competences	Science	V	X	V	V	Almost completely consistent
	Technology	V	V	V	V	Consistent
	Engineering	V	X	V	V	Almost completely consistent
	Art	V	V	V	V	Consistent
	Mathematics	V	V	X	V	Almost completely consistent
Ability to create the special topic product		–	–	V	V	Consistent

“–” indicates zero quantitative analysis; “V” indicates positively significant; “X” indicates nonsignificant

This research team and the teachers conducted further analysis of the items with partial consistency. After the 18-week iSTEAM course, the technology senior high school students studying electronic science in the case school showed increased competence in science, engineering, and mathematics skills; however, only some of the quantitative analysis results were consistent. After an in-depth discussion, this research team and the teachers agreed that pretesting should be placed in Week 1 of the 18-week iSTEAM course, rather than in Week 12, when Unit 3 (Special topic: iSTEAM-developed wearable devices for pets) began, and the reasons for this are as follows. First, most of the students had obtained basic knowledge and skills after studying Units 1 (Application of LEDs and Sensing Switches) and 2 (Application of LEDs and Temperature and Humidity Sensing). This can be taken as an important basis for the improvement of this special topic course. Second, the students were not as satisfied with their gains in mathematics competence. This result is inconsistent with that of the above STEAM competences and shows that the students’ application of mathematics competence was outpaced by their confidence in their own mathematics competence. This result indicates that the special topic course enriched the students’ mathematics competence in subtle ways (Weatherly et al. 2017).

In summary, this study’s research objects were technology senior high school students taking a special topic course in electronic science at the case school, and the study examined the experimental teaching results of a project involving iSTEAM-developed wearable devices for pets. Therefore, the course planning and research results provide a reference only for the imagination and STEAM integration course planning in engineering subjects at a technology senior high school, and it is not advisable to excessively generalize the research to other fields, which is a limitation of this study.

Conclusions and suggestions

Based on the research results and the discussion, this study draws the following conclusions and puts forward the following suggestions for teaching:

Conclusions

Designing special topic activities based on real world issues helps integrate imagination with STEAM education

The iSTEAM course in this study took a topic applicable to the students' real-life experiences, ultimately selecting wearable devices for pets as the main focus of the STEAM learning project, and explored the STEAM knowledge connotations related to this topic as the basis for the activity design. Moreover, a set of 6 tasks were planned based on the 6 iSTEAM subjects to guide the exploration of the needs of pets and owners, the compromise between function and appearance in product design, and problem-solving activities and to guide the students through an interdisciplinary learning process to integrate STEAM theory and practice in hands-on activities that enabled students to construct meaningful learning from practice.

The iSTEAM course can significantly improve the ability of most technology senior high school students to apply their imagination to real-world problems

In this study, students were invited to carry out peer evaluations and grade the work of the other groups in terms of the application of imagination. The evaluations included the three key points of the appearance modeling of imagination, functional imagination, and value imagination. After the iSTEAM course, the students' STEAM-related knowledge and ability to create wearable devices for pets was more established, and the designs' appearance, function and electromechanical integration were practically tested and modified based on the students' prior experiences. Most of the technology senior high school students said that the application of imagination positively and significantly improved their ability to develop their work. They all believed that the wearable pet devices they designed had diverse and practical functions, as well as attractive and creative appearances, thus meeting the needs of pets and being worthy of promotion.

The iSTEAM course had a significant positive effect on technology senior high school students' technology, art, and mathematics abilities and a partial positive effect on their science and engineering abilities

According to the above discussion on iSTEAM learning, the imagination of technology senior high school students enabled them to exceed the limitations of existing conditions, develop many different designs for wearable devices for pets, and obtain a higher level of STEAM knowledge than they would otherwise have. Moreover, in the process of applying imagination to practice, the students repeatedly used the techniques of exploration, brainstorming, association, transformation, connection, and explicitness to solve problems, which strengthened their ability to integrate and apply STEAM knowledge.

Although the results of pretest and posttest quantitative analysis did not show significant improvement in the students' science and engineering knowledge, the peer evaluation analysis of the groups' work indicated that the students perceived significant improvement, and the qualitative analysis of the creation process of the devices clearly showed the practical application of students' scientific knowledge and engineering design skills: various scientific principles, such as temperature, humidity, and brightness; scientific knowledge,

such as infrared, ZigBee, Bluetooth, WiFi, and other wireless communication technologies; and engineering skills and abilities, such as problem solving, creative thinking, modeling design, structural design, and blueprint drawing.

Integrating imagination into STEAM learning activities can significantly enhance students' imagination stimulation, project-development ability, and learning satisfaction with STEAM competences

The research results show that the iSTEAM course can effectively promote the performance of students' iSTEAM work, which is a skill highly praised by experts; most of the students believed that the iSTEAM course could improve their imagination, project-development ability, and STEAM competences, as shown by significantly positive results. It is shown above that the iSTEAM learning activities in this study guided students to use their imagination to transcend the limitations of realistic conditions. It was helpful for students to explore and apply higher level STEAM knowledge by understanding actual interactions, examining the demands between owners and pets, and boldly considering possible innovative designs for wearable devices for pets. In addition, in the mutual transformation process between imagination and implementation, the students repeatedly practiced identifying problems, solving problems, and verifying the feasibility of schemes, which is conducive to the STEAM learning goals of integrated knowledge and application.

Planning the iSTEAM course using the design research method is helpful in enhancing the integration of imagination and STEAM education

According to this research and analysis, most of the students believed that their work showed a significantly positive application of imagination and performance of STEAM competences, and there was a significant moderate correlation between the two. Moreover, the peer evaluation of the iSTEAM performance of the 8 student groups was highly correlated with the expert scores; this shows that the iSTEAM course, as planned using the design research method and including the four stages of preparation, implementation, evaluation, and popularization, is helpful in integrating imagination into STEAM education and thus enhances students' interest and initiative in learning. Furthermore, the results of the iSTEAM course show that students' imagination and STEAM performance can be strengthened through the course activities, which helps improve the quality of the students' creativity in the design of wearable devices for pets.

Suggestions

Use the iSTEAM course to cultivate technology senior high school students' imagination and STEAM knowledge learning

According to the research results, the iSTEAM course can improve students' imagination and their acquisition of STEAM knowledge. Therefore, it is suggested that in developing special topic courses, teachers can incorporate the following into their curriculum: the iSTEAM course, real-life topics familiar to students, emerging technological elements, and the 6 iSTEAM tasks and STEAM-driven issues. In this manner, teachers can guide students to acquire and apply STEAM knowledge, strengthen students' ability to solve

problems in a flexible and creative manner, and spark students' interest in interdisciplinary courses and professions.

Plan the iSTEAM course using the design research method to deepen teachers' energy in implementing special topic courses

The analysis of the feedback on the students' learning process during the iSTEAM project found that teachers can systematically integrate imagination and STEAM into special topic activities by using the design research method to plan iSTEAM courses; for example, students can stimulate their imagination, apply STEAM knowledge and emerging technologies to solve problems in different fields, and design diversified and practical products through the guidance of the 6 tasks of the iSTEAM course. Therefore, it is suggested that teachers adopt the design research method as a tool to plan iSTEAM courses in order to examine the completeness of the planned learning activities at all stages and thus strengthen teachers' ability to integrate STEAM education and imagination and accumulate iSTEAM teaching energy, which will improve the quality of their application of emerging technologies in their teaching.

Incorporate emerging technologies and real-life issues into iSTEAM courses

According to the research results, most of the students were satisfied with the iSTEAM course; for example, they showed motivation to learn about emerging scientific products and technologies, designed new products, and became interested in solving problems for pets like those they lived with. Therefore, it is suggested that in response to the trends of the digital era, teachers include interesting and practical life issues in the design of iSTEAM courses and incorporate the use of emerging technologies in such courses. Using technology and real-life issues will make it easier for students to put their STEAM knowledge and imagination into action and turn iSTEAM courses into interesting special topic courses for the diversified learning and development of students.

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