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English-learning mobile app designing for engineering students' cross-disciplinary learning and collaboration: A sample practice and preliminary evaluation

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Engineers must be able to collaborate with experts across disciplinary boundaries to successfully address the complex challenges of a contemporary workplace. As programming has a reflexive synergistic character, it can support a way of thinking about and exploring disciplines beyond computer science. Meanwhile, programming is a medium of communication. In this study, engineering students used authoring tools of mobile app to design an English-learning app, in which English teachers provide feedbacks for revision, and a preliminary cross-disciplinary collaboration is asserted. The learning design referred to the frameworks of constructing socio-technical creativity to aid the students in employing their existing English knowledge to design mobile apps. The evaluation was conducted on the basis of the students' designed apps and presentation, teachers' feedback, and students' self-reports. The results indicated that the common use of mobile apps in daily life seemed to create a boundary object for the engineering students and English teachers to express, communicate, and coordinate their perspectives and knowledge. Students could view the engineering work from different aspects and value English teachers' expertise. By accounting for the interests of students and schools' limited resources, this study serves as a reference for developing a method of cross-disciplinary learning and collaboration.

Implications for practice or policy:
- Students can acquire knowledge of English as well as programming skills in an instructional software design activity.
- Cross-disciplinary collaboration could be enhanced by using mobile application as a boundary object.
- Teachers could use instructional software design activity to promote cross-disciplinary learning and collaboration for engineering students.

Keywords: authoring tools, cross-disciplinary, boundary object, engineering, programming

Introduction

Engineers have been criticised for being particularly unlikely to consider other perspectives, a trait required for cross-disciplinary collaboration (Marmaras & Nathaneal, 2005). If engineers fail to consider other disciplinary perspectives, they may undermine any cross-disciplinary collaboration they are involved in (Borrego & Newswander, 2008). This is more problematic in an information society, because engineers have to consider multiple perspectives when addressing problems to ensure a comprehensive solution (Borrego & Newswander, 2008; Davis, 1995). Thus, in addition to developing a deep understanding of their own discipline, engineers must be able to collaborate across disciplinary boundaries to address the complex challenges inherent in contemporary workplaces (Richter & Paretti, 2009). Engineering students often lack the ability to connect interdisciplinary subjects to their own fields of expertise and fail to identify and value the contributions of multiple fields to complex problems. Therefore, cross-disciplinary collaboration is vital to engineering education.

Cross-disciplinary collaboration begins with recognising the need for expertise in an area beyond one's own disciplinary training (Borrego & Newswander, 2008). At university level, cross-disciplinary courses focus more on employing multiple perspectives and relating information to a larger conceptual framework than on the concerns of a single discipline (Davis, 1995). Cross-disciplinary studies prepare students for work and citizenship by developing high-order cognitive skills and the ability to employ multiple perspectives (Lattuca, Voigt, & Fath, 2004). Programming has been treated by education researchers as a medium; that is, a way of thinking about and exploring disciplines beyond computer science (Psycharis, Botsari, Mantas, & Loukeris, 2014; Soloway, 1993). Computational thinking requires students to not only write code but also have the code achieve specific and desired results in a discipline. Consequently, students must have a conceptual understanding of and logical reasoning in how computer programming is related to that discipline. Programming is a medium of communication that can be used to facilitate students' construction of knowledge of other domains (Harel & Papert, 1990). The reflexive synergistic quality of programming seems to offer unique educational potential for cross-disciplinary learning (Harel & Papert, 1990). For example, when writing code for English learning applications, engineering students apply programming skills alongside various language skills (reading, writing, listening, and speaking) and language areas (pronunciation, vocabulary, and grammar) using a wide range of methods.

Flexibility and adaptability are essential competencies in the context of collaboration and teamwork (Barak & Levenberg, 2016). Consideration of multiple perspectives and the ability to make changes in one's thoughts or beliefs is termed *cognitive flexibility* (Garner, 2009), through which people can spontaneously restructure knowledge. Cognitive flexibility is an adaptive response to radically changing situational demands (Spiro & Jehng, 1990). People must become "open and fair minded, flexible in considering alternative opinions" (Griffin, McGaw, & Care, 2012, p. 40).

Astin (1993) noted that enrolling in a cross-disciplinary course was positively correlated with self-reported growth in preparation for graduate or professional studies. A combination of cross-disciplinary topics and intentional pedagogy may promote learning to a greater extent than each individually (Lattuca et al., 2004). An optimal pedagogy can promote the development of sophisticated knowledge and should challenge students to recognise, evaluate, and select among multiple perspectives (Borrego & Newswander, 2008; Lattuca et al., 2004). However, little research has focused on concrete interventions supporting cross-disciplinary development in engineering education (Richter & Paretti, 2009), and understanding the contributions of cross-disciplinarity and pedagogy in actual educational settings is challenging (Lattuca et al., 2004).

As engineers must be able to collaborate with experts across disciplinary boundaries to successfully address the complex challenges of a contemporary workplace, related training and courses are needed to fulfil such needs. This study echoed such needs and proposed the use of instructional software design activity to promote cross-disciplinary learning and collaboration for engineering students. A programming course was designed requiring engineering students to use authoring tools to design an English-learning app, during which English teachers provided feedbacks for revision. The course was conducted in an engineering department of a comprehensive university in Taiwan. The students' mother language was Mandarin Chinese, and English was taught as a foreign language during their six-year secondary school study. As to the programming language, students had at least two credit hours for one semester in their high school training, which is prescribed in the curriculum guidelines by the Ministry of Education (2009). However, students' programming skill was not a concern in this study since the selected authoring tool and the assigned term project did not require advanced skills for university students. Such basic skill was a feature in this study, which could help students focus on cross-disciplinary learning and collaboration in a regular course. This study set out to show that the simple development platform provided by the engineering authoring tools and experience of English learning may help students proceed their design with two disciplinary domain knowledge, engineering authoring and English learning. The study aimed to help students experience a generative process that involves creative and reflective thinking through cross-disciplinary training. The common use of mobile apps was intended to help the engineering students and English teachers express, communicate, and coordinate their perspectives and knowledge. Such interaction aimed to foster students' positive attitude towards cross-disciplinary collaboration. The research question is whether students can perform creative and reflective thinking and build up a positive attitude in the proposed cross-disciplinary learning practice.

Literature review

In an information society, students must develop the capacity to cope with multiple perspectives (Davis, 1995) and be able to see, evaluate, and select from among various perspectives. The related training is conducted through cross-disciplinary courses, emphasising the development of holistic views of reality through multiple disciplines (Lattuca et al., 2004). Cross-disciplinary courses have three types of instructional design (Lattuca et al., 2004):

- *informed disciplinarity*, in which instructors focus instruction primarily on a single discipline but call upon other disciplines to illuminate course content;
- *synthetic interdisciplinarity*, in which instructors combine theories, concepts, and research methods from different disciplines, but the contributing disciplines remain clearly identifiable, revealing relatively bounded content areas and distinctive methods of inquiry; and
- *transdisciplinarity*, in which the disciplinary sources of theories and methods are synthesised and applied across disciplines until they are no longer associated with a single discipline. Transdisciplinarity may be embedded with real-world problems and conducted through a situated learning context, in which students are engaged in authentic tasks similar to those they are expected to perform as workers (Lattuca et al., 2004).

In addition to being able to cope with multiple perspectives, students must also be able to collaborate with people with different areas of expertise. The common focus of cross-disciplinary collaboration is differences in the use of terminology (Borrego & Newswander, 2008). However, a more fundamental challenge is the manner in which people understand and appreciate the nature of knowledge across disciplines (Borrego & Newswander, 2008). Thus, instilling positive attitudes in students is the primary learning goal of cross-disciplinary collaboration.

Borrego and Newswander (2008) categorised collaboration into two types of interaction: *multidisciplinary collaboration* and *truly interdisciplinary approaches*. The multidisciplinary collaboration approach limits the exchange of information, and the collaborators consequently leave the project without learning much about the other disciplines. Thus, each collaborator continues on an independent trajectory relatively unchanged by the experience. Truly interdisciplinary approaches require participants to work closely together towards a solution. At the end of such collaborations, each participant is changed by the experience, understanding and appreciating the contributions of the various disciplines and participants (Borrego & Newswander, 2008). A truly interdisciplinary approach should be adopted in education. However, as cross-disciplinary learning and collaboration require the resources of experts from various fields, it is a challenge for most university engineering courses.

In addition, the study intended to promote students' positive attitude towards cross-disciplinary collaboration the idea of holding various ways of thinking towards different domain knowledge. We selected the four-level framework proposed by Adams, Forin, Srinivasan, and Mann (2010) because it provides increasingly advanced methods of experiencing and comprehending cross-disciplinary practice, in which the attitudes and perspectives of a successful collaboration are clearly delineated.

Level 1: Working together to determine optimal solution

Participants must be comfortable with asking for information that might seem obvious. Group members know what they and others contribute and recognise differences in knowledge and how people communicate.

Level 2: Intentional learning to ensure everyone gains

This level of learning creates opportunities for participants to learn new perspectives and purposefully educate each other to collectively enable a systems perspective. Participants must learn how to negotiate meanings across perspectives and formulate or investigate problems through multiple lenses.

Level 3: Applying learning to enable cross-disciplinary work and outcomes

At this level, participants make conceptual connections among issues or topics from different disciplines, enabling the creation of systems-oriented strategies and frameworks that leverage diverse perspectives.

Level 4: Transformative reflective practice challenging previous training and ways of thinking

Cross-disciplinary practice integrates systems and produces an outcome greater than the sum of its parts. In such practice, conflict resolution can be transformative. Collaborators are attuned to the human aspect of complex systems. Practice stakeholders can be integrated as collaborators.

Social creativity and boundary objects

The creation of a learning environment for building up students' positive attitudes towards cross-disciplinary collaboration work needs to be guided by the overarching goal of social creativity. Harrington (1990) related it as the emphasis of collaborative activities, within which people have unique ideas or apply existing ideas to new contexts and these ideas must be expressed to enable evaluations wherein other people from different disciplines and perspectives can understand, reflect, and improve (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2005). Meanwhile, social creativity can be further encouraged by the effects of social reward, credit, and acknowledgment (Fischer, Scharff, & Ye, 2004). In an engineering course, sharing creative ideas requires appropriate socio-technical settings fostering a shared understanding and helping group members use others' knowledge or imagination (Fischer et al., 2005; Hansen, 1999; Kim, Park, Yoo, & Kim, 2016; Lam, 2000). People are more likely to generate creative ideas when they can access a diverse range of knowledge by interacting with other people with dissimilar expertise (Kim et al., 2016; Sosa, 2011).

To support social creativity, because of advances in technology, learning design may have collaborators create socio-technical artefacts, the so-called boundary object in cross-disciplinary collaboration (Star & Griesemer, 1989), to help them externalise tacit knowledge and promote distributed cognition (Fischer et al., 2005). Boundary objects are present in the spaces where different disciplines meet and individuals and groups are involved in collaboration. Boundary objects communicate and coordinate the perspectives of various constituencies; each constituency has only partial knowledge and partial control over the interpretation of the object (Arias & Fischer, 2000; Bowker & Star, 2000; Fischer et al., 2005). Boundary objects have flexible definitions; consequently, each discipline can attach its own meaning to the objects, bringing collaborators together and facilitating projects and outcomes (Barrett & Oborn, 2010; Shanahan, Burke, & Francis, 2016). Thus, collaborators are grouped around an object with different meanings for each participant but sufficient shared understanding to proceed. Because each member works on or with the object in their own manner, the group can proceed and accomplish meaningful outcomes (Shanahan et al., 2016).

The boundary objects could be designed and created by students to help them externalise their creativity and intuition, and the boundary object should (1) cause students to move from a vague mental conceptualisation of an idea to a more concrete representation of it; (2) create situational baulk-talk and make thoughts and intentions more accessible for students to reflect on; (3) be a record of students' mental efforts, one that is external rather than in memory; (4) provide a means for students to interact with, react to, negotiate around, and build upon an idea; and (5) contribute to a common language of understanding among participants (Fischer et al., 2005).

Proposed learning design

The proposed learning design had two phases. The first phase aided the students in employing their existing English knowledge to design mobile apps. A mobile app is an engineering work supporting all kinds of applications in various disciplines. The growth of authoring tools and mobile devices can empower students to design the apps through their own creativity and programming knowledge.

In the second phase, English teachers evaluated the apps and provided feedback, and preliminary cross-disciplinary collaboration among English teachers and students was assumed. Students needed to integrate their knowledge of computer programs with the subject content of English and instructional design, in which English teachers were the experts. Meanwhile, the principles of boundary objects and social creativity were adopted to frame the learning design.

In brief, this study's learning design was a tandem structure: *intra-person*: authoring mobile applications for the purpose of English learning; and *inter-person*: collaboration in the format of feedback from English teachers.

Authoring tool

Smartphones and mobile app authoring software were employed as teaching tools to increase the students' engineering skills. Smartphones are common devices used by almost all students. Thus, students already had a level of operational familiarity and interest in mobile apps. The authoring tool used in the present study, App Inventor, was invented by the MIT Center for Mobile Learning (Morelli, Uche, Lake, & Baldwin, 2015), and it is a blocks-based visual programming language enabling people with little or no previous programming experience to create mobile apps for Android devices. The tool aims to transform the complex language of text-based coding into graphical, drag-and-drop building blocks. Students can quickly build apps without worrying about syntax errors.

Computer program design

A computer program consists of a logically arranged set of programming statements and commands that defines the operations to be performed by a computer (Harel & Papert, 1990). Programming is about not only writing code but also writing code that achieves specific and desired results, such as learning English. Instructional software is a collection of programs evolving through the consideration of the interaction between the software and the learner, including raising questions, anticipating learners' responses, and providing explanations and feedback (Harel & Papert, 1990). In this study, the engineering students were required to conceptualise the many computer procedures or routines that were connected to each other for supporting the interactive process of language learning. The students also needed to be trained to consider the multiple routes a user might select and the nonlinear interaction pattern between learners and apps. The corresponding training is illustrated in Figure 1, which depicts the input and output screen, program flow, and code, through which students perceived the entire programming design. Hence, when writing codes, the engineering students needed to combine knowledge of programming, the English subject content, and instructional design (Harel & Papert, 1990). Such learning design was to engage engineering students into working with English teachers in a favourable manner and build up a positive attitude towards cross-disciplinary learning and collaboration.

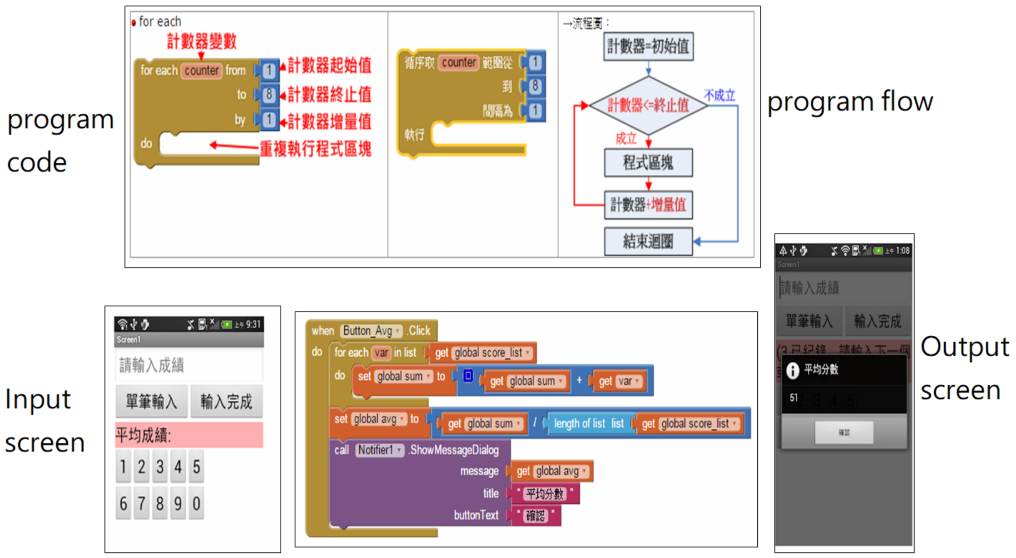

Figure 1. Diagram displaying the input and output screen, program loops, and code

The students were required to present both the source code that would perform their proposed language-learning app and a schematic representation of the programming logic used. By organising all the information into hierarchies, the relationships between isolated programming code and the application flow could be reviewed, enabling the students to create a more coherent language-learning process.

Mapping app techniques with language-learning interactions

Students were instructed in two basic interactive modes of language learning. The first was a learner's receptive mode, in which applications provide instructions to learners. The second was a learner's productive mode, in which learners follow instructions and respond accordingly. With the two modes combined in an application, learners can experience interactive, receptive, and productive communication. The receptive mode enables the application to play a sound file of a sentence being read or to display a word on screen, whereas the productive mode can record learners' pronunciation or enable learners to write text. Thus, versatile approaches to learning were employed on the basis of the two modes of human–computer interaction and four language skills (namely listening, speaking, reading, and writing).

Smartphones can support advanced processing of multimedia (e.g., speech recognition, text to speech, and text translation) (Ting, Tai, & Chen, 2017; Ting, Tai, Tseng, & Tsai, 2018). These functions enable simple development of versatile language-learning applications. For example, learners can be given vocabulary within the app on their smartphone, and the app can listen to them pronounce the word while using the in-built speech recognition to detect the accuracy of their pronunciation and provide feedback. In the present study, the students were trained to acquire and apply these techniques in their designed apps. They were also encouraged to follow the four elements of creating creativity (Fischer et al., 2004) and to base the app on their own English-learning experience.

Research method

The study was held in a university 18-week elective course titled "Mobile Technology and Applications," which had 37 junior and senior engineering students. The students formed 10 teams (an average of 4 people per team). Four teams of students with ethical clearance for all the members became participants in this study. Their work was used for research purpose. Data sources were students' written self-reports, presentation slides, mobile apps in the group work format, voice recordings of interactions among students and between students and English teachers in classes. The voice recordings were transcribed into texts for further analysis.

The students had received formal English teaching for at least 10 years over the course of their K–12 education. The students were informed that each team had to create a project, an English-learning mobile app for use in elementary schools. The elementary school level was chosen because the participating students' training in the authoring tools was basic.

The students were trained to use the mobile app authoring tools and the related programming techniques for the four language skills outlined in the previous section. At midterm (9th week of the 18-week course), the students demonstrated their design and implementation. The demonstration was evaluated by an instructor to ensure that the students had developed a complete and standalone English-learning app.

After midterm, the students were introduced to the use of flow charts in computer programming and how they relate to a mobile learning app, which facilitated the construction of more complex mobile applications without logistic errors or programming flaws. In addition, the students were provided with web resources regarding educational apps to encourage them to improve their design and stimulate new ideas.

At the 16th and 18th weeks of the course, two elementary school English teachers were invited to the classroom to help the students improve the app; this served as simulated cross-disciplinary collaboration. In the 16th week, the students presented the preliminary version of their English-learning app. In the presentation, the students were asked to use the overhead projector to enable their classmates and the English teachers to watch their live demonstration and provide quick response (QR) codes for everyone present to download the app and gain first-hand experience. After each group presentation, the two English teachers provided feedback based on their expertise and the usability of the designed mobile app. This feedback was designed to promote collaborative discussion and bring stakeholders' thoughts and intentions into focus for everyone to reflect on. Nine generic usability attributes can be employed to measure the quality of an application (Öquist & Goldstein, 2002; Zhang & Adipat, 2005; Ziefle, 2002). Considering the possibility that too many items would overburden and confuse participants and that too few items would not lead to sufficient discussion, only five of the nine attributes were selected. The five selected attributes were *simplicity*, *comprehensibility*, *user satisfaction*, *learnability*, and *learning performance.*

To ensure the sustainability of the students and English teachers' discussion and social appreciation (i.e., the effects of social reward, credit, and acknowledgments by others), all participants were told that their comments were to be recorded, transcribed, and delivered to them in text format in the next meeting. With these instructions, the students' app presentation and transcribed comments, the participants' ideas could transform from a vague mental conceptualisation into a concrete learning artefact, providing a common language of understanding for others to interact with, react to, negotiate around, and build on. The students' self-designed apps served as boundary objects (Arias & Fischer, 2000; Bowker & Star, 2000; Fischer et al., 2005), externalising tacit knowledge, communicating, and coordinating the perspectives of various constituencies to support social creativity and promote distributed cognition (Fischer et al., 2005).

In the 17th week, the students were provided with the English teachers' transcribed comments for improving their English-learning apps; however, the students may have begun revising their apps after listening to the teachers' oral feedback. The students were also provided with guidelines on how to report their responses to the cross-disciplinary learning practice.

In the 18th week, the students presented their newly revised English-learning mobile app and explained the changes they made and how they made them. The English teachers commented on whether the revised app met the requirements. The students then provided their responses to the cross-disciplinary learning practice.

Because of the limited time for the interaction between the engineering students and the English teachers, only the first two levels of Adams et al.'s (2010) framework were adopted to guide students' self-reports: working together to determine optimal solution and intentional learning to ensure everyone gains. Each level consists of five attributes (Adams et al., 2010, pp. 1160-1161), which has been adapted and rephrased to fit into the context of this study. For the second level, five attributes have been merged into four attributes.

The first level has five attributes:

(1) Identify the knowledge and skills you bring to the project.
(2) Recognise the project goals and constraints of team members from other disciplines.
(3) Have confidence in your current ability to contribute to the project.
(4) Have confidence in your ability to engage in discussions with team members from different disciplines.
(5) Have confidence in your ability to understand how different disciplines contribute to the project.

The second level consists of four attributes:

(1) Gain any new perspective of your own knowledge and skill.
(2) Gain new perspectives or knowledge of other disciplinary.
(3) Better understanding of cross-disciplinary work.
(4) Perform better in future cross-disciplinary work.

Based on the nine attributes, the researchers developed the questions to guide students' self-report of their responses to the proposed learning practice. The questions are listed in the Results section. After collecting all of the students' self-reports, qualitative analysis of the reports for emerging themes was conducted by the two researchers. The terms used in the themes reflected as closely as possible the participants' own terms (Girvan, Conneely, & Tangney, 2016) and highlighted the voices of the participants. Confusing points or disagreements were clarified and resolved through discussion.

Examples of students' work

The results included the students' final app and reports regarding the cross-disciplinary learning process. Examining the students' apps, the results indicated that the students understood the association between programming flow and language skills, and how a mobile app interface should be constructed. In addition, the students also adopted web resources to enrich their apps. For example, Figure 2 presents an example of code created by the students for recognising the users' voice and translating it into a language selected by the user, rather than only Chinese or English.

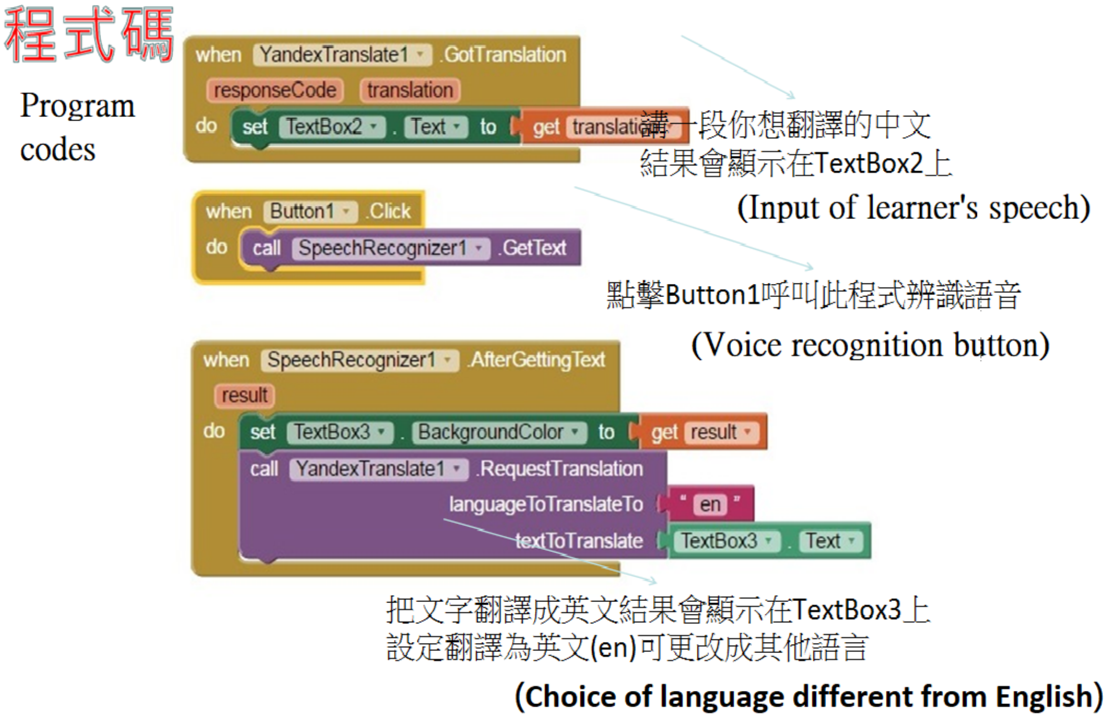

Figure 2. Code translating Chinese voice input into English output or another language (students' slide)

Students exercised their creativity in designing the apps, four examples of which are illustrated herein. The first example focused on learning vocabulary related to the animals at Taipei Zoo (Figure 3). Learners could click on the image of an animal and proceed to learn related vocabulary and pronunciation (Figure 4). The English teachers commented that the interface design served a dual purpose: it not only taught the related animal vocabulary but also illustrated where the animals were located in the zoo. The app provided photos of the animals in question as well as provided the sound the selected animal makes when users clicked on the photos. The teachers stated that this helped to increase learners' memory and stimulated their interest. One student suggested adding annotations describing the animal sounds to deepen learners' memory and broaden their knowledge. This suggestion was supported by everyone in the classroom. Such interactions indicated the students' and teachers' mutual understanding and their collaborative contributions in improving the app.

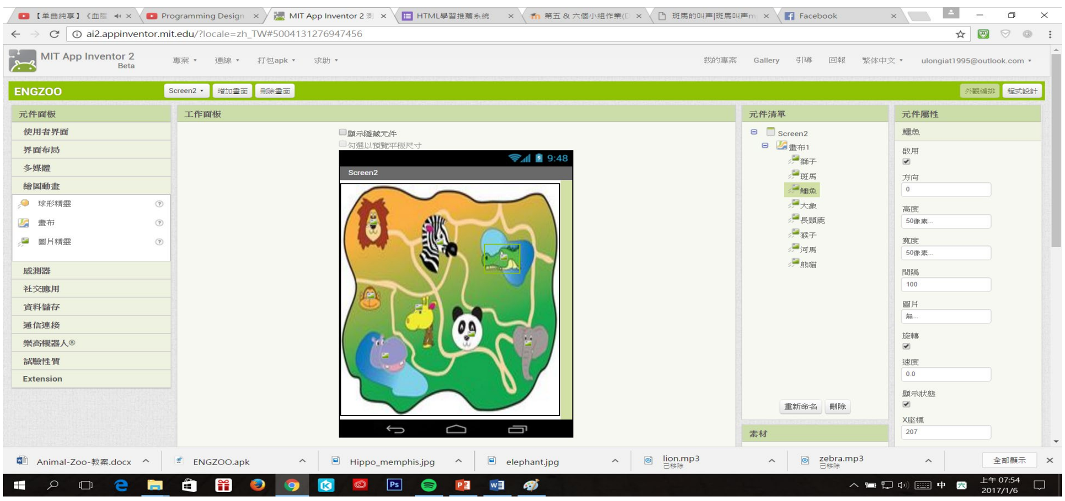

Figure 3. App for learning vocabulary related to zoo animals using a map of Taipei Zoo
Note. All apps were demonstrated within the authoring tool) (example 1).

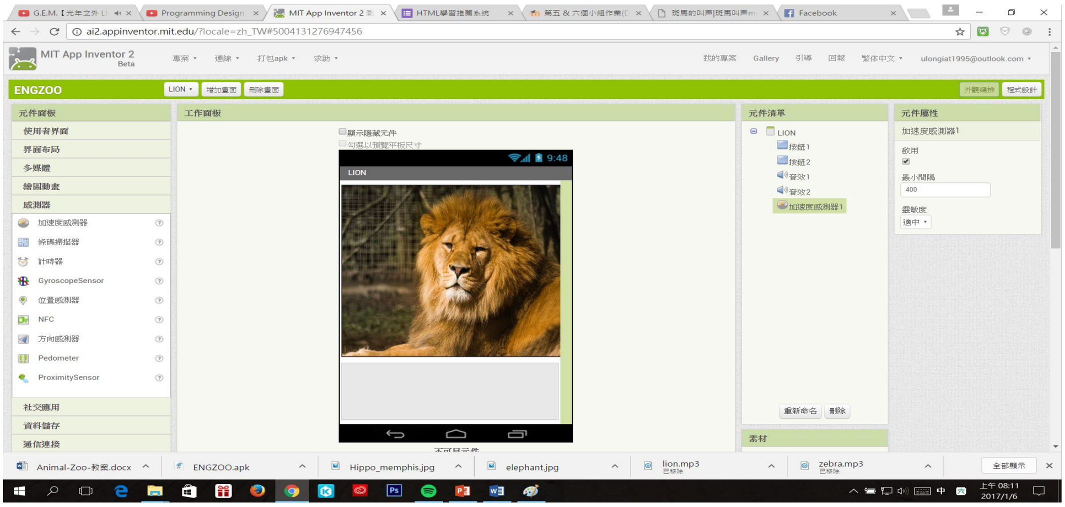

Figure 4. App page for learning lion-related vocabulary (reached by clicking the lion in the upper-left corner of the Taipei Zoo map in Figure 3) (example 1)

The second sample app was also related to animals; however, the app asked learners to practise the four skills of language learning (Figure 5). In the students' presentation, the first two slides welcomed learners and explained the rules for using the app. The next four slides demonstrated how to practise listening, reading, writing, and speaking, respectively, using the app. The students fully adopted the computational functions of the app to process multimedia elements (figures, text, sound) and match them with the four language skills through two interactive modes (receptive and productive), simulating a language tutor. The manner in which the students presented indicated that they could conceptualise how the app would be used to practise language skills.

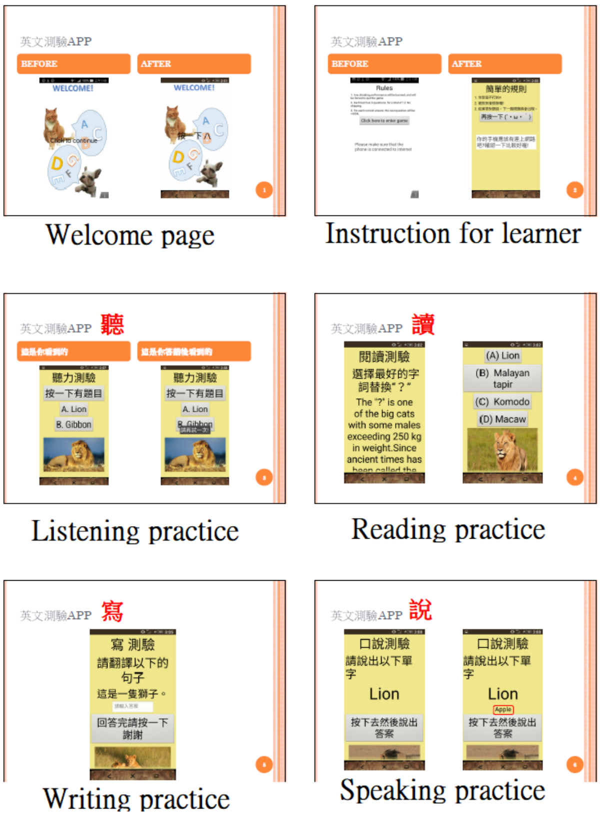

Figure 5. Slides from a presentation explaining how to use one of the students' apps (first two) and the four targeted language skills of the app (last four) (example 2)

The third example (Figure 6) was related to exercise, and the app taught learners through Chinese text associated with pictures that instructed the learner on how to pronounce an English word. Clicking one of the three boxes at the top of the app provided a hint, caused a sound file of the word to play, or enabled the user to check the answer. The students explained that the app associated vocabulary with physical exercise and that pictures of famous individuals could be used to stimulate memory, such as the athlete they had chosen who had just won a gold medal. The English teachers commented that exercise is often an interesting topic for children and using photos of famous athletes can also attract attention. However, they noted that some of the vocabulary exercises were too difficult for children; thus, a word bank was suggested, as was asking children only to recognise rather than recall the words. Following these comments, the class engaged in discussion of recall and recognition and how they are related to the cognitive process of learning and attributed to different learning effects. The students' report later revealed that they enhanced the app by creating dynamic hyperlinks to a web dictionary to help children further explore the vocabulary and a news website that updated the app with the latest sports news every day.

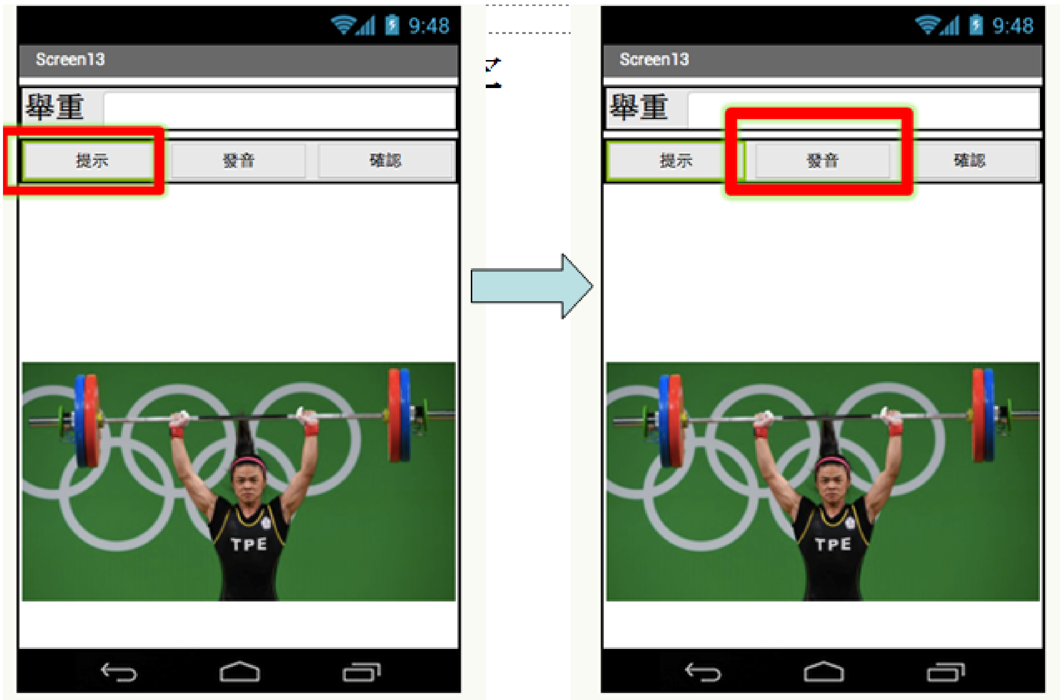

Figure 6. App for learning vocabulary related to exercise (e.g., weightlifting) (example 3)

In the last example, one team transformed the traditional process of language acquisition into a game (Figure 7). Students created images of fish with vocabulary written on them. As the fish swam in the virtual water (i.e., moving on screen), learners were asked to recognise vocabulary and practise pronunciation. The game had three levels of learning difficulty based on the movement speed of the fish. When the pronunciation was correct, the fish with that vocabulary disappeared, and the app played the sound of a fish being caught.

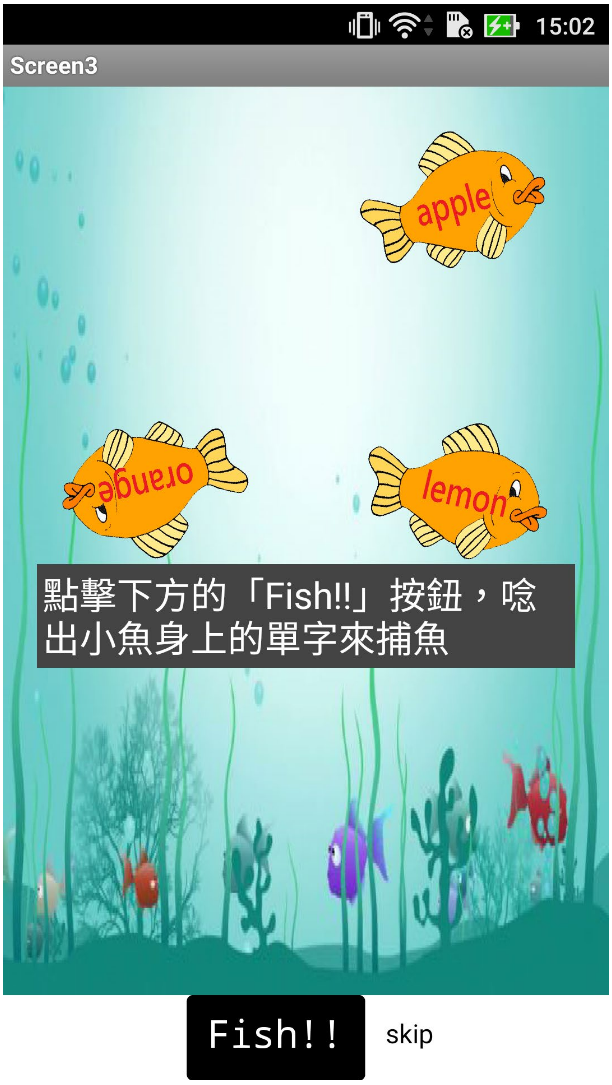

Figure 7. App for practising pronunciation by reading vocabulary from moving fish (example 4)

The English teachers inquired why the fish turned upside down when reaching the end of the screen (e.g., “orange” in Figure 7). The students explained that this was a technical limitation of their app that unintentionally helped make the game more challenging and fun. In particular, the students were trained to code simple image animations (e.g., moving objects). They were also trained to program the speed and direction of the objects they created and make objects bounce when they reached the edge of the screen. This training was part of the app programming tutorial.

The teachers commented that the English-learning difficulty should be adjusted by vocabulary level (e.g., “man” is easier than “elephant”) rather than the speed at which the vocabulary moves on screen. After being informed of their mistake, one student suggested using objects in the water to block the letters on the fish while the learner tries to recall the word. This response indicated that the students could recognise and apply the English teachers’ suggestions in their re-design of app.

Results

The results were obtained from the students’ self-reports, in which participating students answered the questions developed from the attributes of Adam et al.’s (2000) framework. Students’ responses to the nine questions of levels one and two combined were analysed and presented as follows.

Level 1: Working with people from different training backgrounds

1. Can you identify what you can contribute to the design and authoring of an English-learning app?
The students' responses included the following:

> Knowing the authoring tools and how to use them for software development, including program interface design
> How to make learning English fun and easier for students
> How to transform learning content into a digital format including sound, images, and videos and embed them into a learning app
> How to create an app to support tasks that are difficult in a classroom setting (e.g., one-to-one and repetition drills).

These comments indicate that the students were able to identify their technical and pedagogical contributions.

2. Did you understand the English teachers' suggestions and requirements?
All of the students' responses were positive, and they noted that the English teachers' comments were clear following their report and app demonstration. One group reported that the English teachers suggested providing explanations for a menu item to ensure learners knew how to proceed. Another group also noted that the teachers' comments reminded them not to focus too much on the programming flow at the expense of the user interface design. These comments indicated that the students' apps and presentations served not only as a concrete artefact on which participants could understand one another and exchange ideas but also as a platform for collaborative discussion.

3. From the perspective of improving your English-learning apps, were you comfortable interacting with the English teachers?
Students provided positive responses with reasons, such as the teachers providing encouragement, recognition, and recommendations. One group stated that the teachers' comments helped them improve their app, which made them feel comfortable. Another group noted that they were glad to have people comment on their work. The students' comments indicated that the English teachers' experience in teaching and providing students with suggestions contributed to the successful cross-disciplinary collaboration.

4. Did you understand how to use the app authoring tools to meet the English teachers' requirements? Please provide some examples.
All students responded positively with examples from their apps. For example, the English teachers requested that one of the apps be made more accessible to users. The students thus decided to add dubbing to their app, which required them to record an instructional message and add a function to their app for playing the recording. Another similar example was a request to improve the clue provided when guessing animal vocabulary, including the pronunciation and number of English letters for that word. The teachers noted that learners who do not know the answer should have a chance to hear the pronunciation or see several letters to aid them in recalling the vocabulary. Teachers also suggested providing more background knowledge about the animals; for example, the lion could be annotated with "king of the jungle." In addition, the teachers suggested a link titled "Want to learn more? Click here" that led to additional web content related to the learning material.

These results indicated that the students knew how to use the app authoring tools to meet the English teachers' requirements. The authoring tool enabled the students to focus on the pedagogical requirements over technical expertise.

5. Did the input of the English teachers and the app authoring tools support you in designing the English-learning app? Why or why not?
The students' responses varied. Two out of four groups that answered "yes" mentioned that the English teachers provided comments from the perspective of both teachers and learners, highlighting the possible difficulties that learners may face using their apps. The students noted that they felt an effective learning app was subjective. However, in working with the English teachers, they realised that software programs are operated by learners who objectively judge the content. The students noted that objective opinions are thus useful in locating app shortcomings and providing suggestions for improvement.

However, when improved design requires technical performance, the students were likely to answer "no." The students noted that they were unable to change the font used because of the technical limitations inherent in the authoring tool. They noted that they needed to consider how best to employ the available techniques to achieve their apps' learning purpose, rather than allowing the limited design functions to restrict their creativity. These responses indicated that the students recognised the different perspectives of viewing the learning artefact (i.e., the apps) and that ideas based on different perspectives can be valuable. In addition, the students recognised the challenge of using authoring tools, but they attempted to consider it from a learning, rather than technical, perspective.

Level 2: Intentional learning to ensure everyone gains

1. Did you gain any new perspective of computer software authoring tools?
Students from one group reported that they though that they could make an effective learning app without outside experts. However, after their discussions with the English teachers, the students realised that using the authoring tool was just one element; a variety of knowledge and skills is required to produce an effective learning app. Students from another group also mentioned that they used various multimedia tools both familiar and unfamiliar to achieve the task. For example, to create animal images annotated with vocabulary, the students used Adobe Photoshop to trim the digital images and fit them to the interface. To create narration, the students employed the GoldWave software to edit voice sound files to convert them into the correct technical format. These results revealed that the students were not only able to independently learn various multimedia tools to improve their apps but also understood the value of cross-discipline commentary on how to use these tools.

2. Did you gain new perspectives or knowledge regarding learning and teaching English?
Students from one group noted that English-learning apps for children should focus on attracting attention and providing an interesting story. Another group reported that the app should encourage children and provide them with a sense of achievement. To this end, they created different game levels for their users. One group noted that learners should be provided with clear instructions and a friendly user interface. Students recognised that drill and practice is a suitable pedagogy for beginner learners of English.

The results revealed that despite their lack of teacher training, the students were able to reflect on the pedagogies, curriculum, and context of English-language learning. The students recognised teaching and learning concerns and several groups reported how they used their programming skills to address these concerns. One student even mentioned that the process of making the app had led him to realise the level of English he possessed and possible means to improve. Thus, this project helped the students to reflect on their own English learning and gain new perspectives and knowledge regarding English learning and teaching.

3. Do you think this learning practice provided you with an improved understanding of cross-disciplinary work?
The students reported that after the project, they recognised that they would not have been able to create an effective English-learning app without the experienced teachers' help. The students reported that they learned to view their design from different aspects; for example, one group focused on game design and how to make a learning game interesting and competitive. However, the English teachers were mostly focused on how the game facilitated learning. One group noted that learning to respect the expertise of others and understand their concerns is crucial to collaboratively creating an effective app. Another comment noted that "we learned to evaluate others' comments not only based on the facts presented but also their perspective."

One student wrote that they "learned how to communicate with people from different knowledge domains, especially in terms of how to express the coding techniques we adopted." The students also mentioned that they learned how to apply the English teachers' comments when modifying their apps. Another group stated that "when the English teachers presented their ideas, we had to understand and think about possible methods to support them, including the programming techniques and skills required."

These results indicated that the students gained ideas about their interactional relationship with the English teachers. That is, each side understood the needs of the other from their perspective and attempted to fulfill them using their specific knowledge and skills for a favourable project outcome.

4. Do you think this learning practice will enable you to perform better in future cross-disciplinary work and collaborate for the optimal outcome? Why or why not?
The responses were as follows:

> We can make ourselves more understandable to those from different knowledge domains.
> We are aware of the role that we can play in our future careers and how to make effective contributions.
> When writing apps, we will take others' viewpoints into consideration when communicating ideas with them.

One group provided a more elaborate response:

> Yes, because we know the basics of how cross-disciplinary collaboration works. We also learned how to report our work, accept feedback, and respond to requests. With this experience, we believe that we can now collaborate more efficiently with people from different knowledge domains.

Discussion and implications

The cross-disciplinary collaboration, social creativity and boundary objects are important issues for university students to succeed in modern society, and these issues were adopted to underpin the design of learning activities and the evaluation of learning benefits in the current study. The study proposed the use of computer authoring tools for engineering students to experience a preliminary sense of cross-disciplinary collaboration and build up positive attitude. To prepare for cross-disciplinary collaboration, this study provided an interdisciplinary learning environment, in which students apply programming skills alongside various language skills using a wide range of approaches and methods. As a way of thinking about and exploring disciplines beyond computer science, students improved their accuracy and fluency of English as well as instructional theories for developing English learning apps, for example, the use of the zoo, athlete, and fishing game (Figures 3–7) to present the practice of language skills. The related design indicated students' cognitive flexibility emerging from multiple perspectives. Students were able to recognise, evaluate, and select among multiple perspectives in the domain of English learning and computer programming.

Furthermore, the students and English teachers were able to think of and propose relevant web resources for their own learning scenarios. Teachers are often familiar with web resources and can recognise how they fit in with students' proposals. As for the students, linking such resources relieves them of the need to determine a technical solution, as links can easily be created using the authoring tool. Engineering students and English teachers can base on the mobile apps to express, communicate, and coordinate their perspectives and knowledge. The mobile apps and the web resources seemed to support a shared understanding and enable English teachers' evaluations and comments wherein engineering students can understand, reflect, and improve. These improvements were evidenced in the second round of students' presentation. For example, in the third example related to exercise (Figure 6), the app associated vocabulary with physical exercise. The English teachers noted that some of the vocabulary exercises were too difficult for children; thus, a word bank was suggested. In the revised work, students enhanced the app by creating dynamic hyperlinks to a web dictionary to help children further explore the vocabulary.

The aforementioned collaboration among participants is one example of how students and teachers have only partial knowledge and control over the interpretation of an app, but by interacting with, reacting to, and negotiating with each other, they can build new ideas regarding authoring English-learning apps. Both engineering students and English teachers focused on improving the mobile app from their own perspectives. Authoring apps seem to support the externalisation of tacit knowledge (i.e., programming and English) and support social creativity. The apps in this study were boundary objects addressed in several studies (Arias & Fischer, 2000; Bowker & Star, 2000; Fischer et al., 2005). The results show that common usage of web resources among people and easy-to-use authoring tools, which are rarely used in mobile-technology–mediated learning research, can thus create a boundary object to support cross-disciplinary collaboration in higher education.

Regarding students' self-reports about their responses towards the proposed collaboration, the results illustrated that students built up a positive attitude towards cross-disciplinary work and believed that the learning practice provided support for their future work. According to the first level of Adams et al.'s (2010) framework, students could clearly identify what they could contribute to the design and authoring of an English-learning app, for example, transforming English learning content into a digital format including sound, images, and videos and embed them into the app they authored. In addition, students reported that they could understand how to use the app authoring tools to meet the English teachers' requirements. For example, the English teachers requested that the one of the apps be made more accessible to users, and engineering students responded with adding dubbing to their app.

Regarding the second level of intentional learning to ensure everyone gains, students gained new perspectives on computer software authoring tools. For example, students reported that after receiving feedback from the English teachers, they realised that additional expertise was required to make an effective learning app. Using the authoring tool was just one element; a variety of knowledge and skills is required to produce an effective learning app. Students' improved understanding of cross-disciplinary work was also evidenced in a report that at the beginning they focused primarily on game design and how to make a learning game interesting and competitive. However, after interacting with the English teachers, the students learned that the design focus should be on how the game facilitated learning. Students reported that they learned to evaluate the teachers' comments from their perspective and learned that respecting the teachers' expertise and understanding their concerns are crucial to successfully creating an effective app. These comments support Borrego and Newswander' (2008) and Adams et al. 's (2010) study and seem to indicate that students were positive towards the proposed learning and had built up a positive attitude towards cross-disciplinary collaboration.

By incorporating the intra- and inter-person structure in the course design, the proposed learning practice was implemented using similar time and resource constraints as those faced by most universities, and it seemed to successfully provide a preliminary experience of collaboration for students and build up their positive attitudes. This study seems to be a specific one in engineering education. With the instructional frameworks illustrated, this study should inspire university teachers to examine their classroom teaching from new perspectives and serve as a reference for their learning design.

Limitations and further research

Regarding further study, this study was conducted with only two rounds of formative feedback from English teachers. Thereafter, only the first two of Adams et al.'s (2010) four levels of cross-disciplinary collaboration were evaluated in validating the study results. Tighter collaborative interactions and how these interactions should be designed need to be addressed for helping students make conceptual connections among issues or topics from different disciplines and resolve interdisciplinary conflict in a transformative manner. In addition, a well-designed course activity with rigorous research method and evaluation are needed for examining the effectiveness of learning benefits. Finally, to provide persuasive and generalisable research results, institutes of higher education may set up a special task group with teachers from different fields to collaboratively design and teach some courses to gauge the learning benefits in various fields.

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