Evaluating a Teacher Development Course for Teaching STEM Activities with Introductory Internet of Things Concepts and AI Data Model Training Skills Using the TPACK Framework: Problem-Solving and Digital Creativity

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Keywords: AI Data Model Training, Digital Creativity, Internet of Things, STEM, Problem-Solving, Teacher Development, TPACK Framework.

Abstract: We designed a 6-hour teacher development course aimed at enhancing teachers' competency in teaching STEM activities. The course focused on teaching teachers how to develop learners' problem-solving abilities and digital creativity using both introductory concepts of the Internet of Things (IoT) and artificial intelligence (AI) data model training skills in teaching STEM activities. This study evaluated the teachers' competency in teaching STEM activities and the outcomes of their creative ideas in solving problems using what they had learned in this course. Two hundred and one teachers from 108 primary schools attended the course, of whom 191 responded to the pre- and post-course surveys on the TPACK framework, and 176 of them produced artefacts demonstrating their digital creativity. The paired t-test results indicated statistically significant improvement on all 17 TPACK items, with a large effect size (Cohen's d = 1.213). In the digital creativity evaluation, 82.20% of the teachers demonstrated digital creativity and expressed their ideas in designing introductory IoT systems, and 72.77% of the teachers included AI components in their design. One future research direction is to evaluate primary students' learning outcomes in STEM activities with these introductory concepts of IoT and AI data model training skills.

1 INTRODUCTION

In the dynamic context of today's rapidly advancing technological landscape, smart systems are assuming an increasingly prominent role. Such systems seamlessly integrate artificial intelligence (AI) and Internet of Things (IoT) with a diverse array of sensors and actuators. By collaboratively collecting, analysing, and responding to data, these components enable smart systems to operate autonomously (Al-Fuqaha et al., 2015).

The integration of AI and IoT into STEM education can significantly enhance students' problem-solving skills and ignite their digital creativity, empowering them to solve real-life problems (Kong et al., 2024). It is thus imperative that primary students are provided with more opportunities to understand and engage with today's AI-permeated world (Kim et al., 2021).

Although research has addressed the development of students' AI literacy (Touretzky et al., 2019), the integration of AI and IoT within STEM education remains underdeveloped (Kong et al., 2024). As an emerging technology, AI can induce anxiety, which may hinder its future application and behavioural intention in professional contexts (Wang & Wang, 2022). Educators play a key role in shaping their students' futures by imparting imperative knowledge. To effectively teach and disseminate this new knowledge, they must possess a profound understanding of the subject matter (Hsu et al., 2023). Many educators currently exhibit low self-efficacy in

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participating in in-service teacher education programmes and feel unprepared for AI education. Therefore, enhancing their understanding and mastery of AI applications is essential (Hsu et al., 2023). Additionally, it is important for teachers to comprehend AI concepts, solve problems using AI, be psychologically ready to utilise AI, and understand the ethical dimensions of AI problem-solving (Kong & Yang, 2024).

We therefore propose an innovative approach that incorporates these concepts into primary school STEM activities. Our design focuses on enhancing students' understanding by facilitating the creation of physical artefacts using introductory IoT concepts and AI data model training skills, thus bridging the gap between theory and practical application.

The IoT and AI are increasingly shaping our world and are poised to become an integral part of everyday life in the digital era (Al-Fuqaha et al., 2015). Therefore, it is crucial to introduce these concepts to primary students. We have selected AI and the IoT as the foundation for our STEM activities. By thoughtfully embedding introductory experiences in AI data model training into educational content, we can include AI data model training and interaction in STEM activities. This integration is vital for helping students understand how automated systems are designed, thereby enriching these systems' complexity and enhancing their usability and accessibility. Moreover, these activities can foster digital creativity by enabling students to consider applying these concepts in new contexts.

However, in-service teachers often have limited technological background related to STEM and lack confidence in teaching these subjects; therefore, teacher development is crucial to successfully integrating STEM education into classrooms (Cavlazoglu & Stuessy, 2017; Lo, 2021). This study therefore seeks to answer the following questions:

(1) Which components of the TPACK framework (i.e., content knowledge [CK], technological knowledge [TK], pedagogical knowledge [PK], pedagogical content knowledge [PCK], technological content knowledge [TCK], technological pedagogical knowledge [TPK], and technological pedagogical content knowledge [TPACK]) show the greatest improvements after teachers complete a development course?
(2) How do teachers benefit in terms of their creativity after attending this course, as evidenced by their design artefacts?
(3) What are the most valuable components of the teacher development course?

2 LITERATURE REVIEW

2.1 STEM Education: Fostering Students' Problem-Solving Ability and Digital Creativity

STEM education plays a key role in cultivating students' problem-solving skills. Research indicates that students are more engaged in STEM activities when they create artefacts using technology (Hanif et al., 2019). STEM education encompasses various aspects, such as causal reasoning, sequencing, conditional reasoning, and engineering systems thinking (Sullivan & Heffernan, 2016). These skills are essential for understanding and addressing complex problems. Evidence from the literature demonstrates that STEM activities significantly enhance these abilities, thereby preparing students for real-world challenges.

2.2 A Novel Design of STEM Activities: Integrating STEM with Introductory Iot Concepts and AI Data Model Training Skills

Current STEM activities often lack integration with contemporary technologies, limiting students' exposure to practical applications. As technology rapidly advances, incorporating new concepts into STEM activities can enhance their appeal to students. Integrating the IoT and AI into STEM education not only can enhance learning by providing opportunities for real-world applications but also can promote digital creativity (Kong et al., 2024). The IoT is a network of interconnected devices that gather data and utilise embedded technology to make decisions (Badshah et al., 2023). AI in IoT systems can facilitate human–system interactions, making STEM systems more flexible and interactive (Ghosh et al., 2018). This integration helps students understand complex technologies and apply them creatively, thereby enhancing their problem-solving skills and digital creativity. Therefore, there is a need for novel STEM activities that incorporate the IoT and AI to nurture digital creativity.

The proposed design addresses these gaps by incorporating the IoT and AI into STEM activities, providing students with hands-on experiences that demystify complex systems design and encourage exploration and creativity.

2.3 Six-Step Pedagogy: 'to Play, to Inquire, to Assemble, to Code, to Create, to Reflect'

To effectively implement this novel design, we adopt the six-step pedagogy – 'to play, to inquire, to assemble, to code, to create, to reflect' (Kong, 2023). This approach is designed to provide students with hands-on experience in interacting with STEM systems to stimulate their curiosity, develop their problem-solving skills, and ultimately inspire their digital creativity. The process begins with 'to play', where students interact with the system and develop an interest. This initial engagement naturally progresses to 'to inquire', which fosters a deeper understanding of the underlying mechanisms of the system. Following this, 'to assemble' involves students in the practical task of disassembling and reassembling the system, which enhances their understanding of the concepts of a STEM system. The subsequent step, 'to code', integrates coding and activities, particularly with AI data model training, allowing students to apply their concepts in a practical context. 'To create' empowers students to share their ideas on building a new STEM system using the technologies they have explored. Finally, 'to reflect' involves encouraging students to consolidate their learning experiences and concepts about IoT and AI data modelling skills. This comprehensive pedagogy can be effectively implemented in classroom settings, providing a robust learning experience that significantly enhances students' problem-solving abilities and digital creativity (Kong et al., 2024).

2.4 Guiding and Evaluating Teacher Development with the TPACK Framework

In this study, we utilise the TPACK framework (Mishra & Koehler, 2006) to design a teacher development course aimed at equipping teachers with the essential knowledge and skills for implementing STEM activities. The TPACK framework comprises seven components, including three primary domains: CK, TK, and PK. The interactions between these domains create PCK, TCK, TPK, and TPACK. In the STEM activities, CK pertains to introductory IoT concepts, AI data model training skills integrated into the STEM activities, and the problem-solving skills required to develop the STEM systems. TK encompasses general proficiency in using technology, including computers, coding platforms, microprocessors, and various electronic components. PK involves instructional strategies for teaching the STEM activities, such as guiding students in using discussions and group activities to navigate the problem-solving process and generate ideas for digital creativity.

3 METHODOLOGIES

3.1 Participants and Procedure

Two hundred and one teachers from 108 primary schools in Hong Kong joined the 6-hour teacher development course. One hundred and ninety-one teachers finished the pre-course and post-course TPACK surveys, of whom 119 (63.30%) were male and 72 (37.70%) were female. In addition, 110 (57.59%) of teachers taught mathematics, 28 (14.66%) taught general studies, 25 (13.09%) taught English, 22 (11.52%) taught Chinese, and 6 (3.14%) primarily taught information technology. Of these teachers, 176 expressed their digital creativity ideas in writing and sketches after the course. A course evaluation form was also used to collect their views on the course.

3.2 Instruments

3.2.1 Teachers' TPACK Survey

In this study, we developed a survey tool for teachers to self-assess their competency in delivering STEM education fused with IoT concepts and AI components within the TPACK framework. The survey comprises 17 TPACK items, each rated on a 5-point Likert scale ranging from 1 (indicating strong disagreement) to 5 (indicating strong agreement). All 17 items are listed in Appendix I of this paper. Our assessment of the instrument's reliability, conducted using Cronbach's alpha analysis, revealed strong internal consistency, with values exceeding 0.85 for both the pre-course survey ($\alpha = 0.97$, $N = 201$) and the post-course survey ($\alpha = 0.98$, $N = 191$).

In addition to understanding how TPACK pertains to the organization of learning and teaching, it is crucial to explore methods for nurturing students' digital creativity in solving real-life problems. NACCCE (1999) distinguishes between teaching creatively, which involves the teacher's own creativity, and teaching for creativity, which focuses on developing strategies that foster learners' creativity. To effectively nurture students' creativity, teachers must employ both approaches (Craft, 2005, p. 44). Additionally, teachers must demonstrate their ability to cultivate ideas and transform knowledge into solutions for real-life problems to promote creative problem-solving using technology.

3.2.2 Written and Drawn Artefacts

Following the completion of the course, the primary school teachers were invited to propose novel STEM applications. These design artefacts were used to gain insight into the advancement of the teachers' digital creativity after taking the course. The criteria for evaluating the creativity of these artefacts are presented in Table 1.

Table 1: Criteria for evaluating the creativity of the artefacts proposed by the teachers after the course.

Criteria	Mark
New STEM application designs incorporating the introductory IoT concepts of sensing, reasoning, and reacting	2
The clarity of the STEM application description could be improved	1
Ideas that closely resembled the STEM applications discussed in the course	0

3.2.3 Course Evaluation

The evaluation instrument for the professional development course consists of 16 questions rated on a 4-point Likert scale ranging from 1 = 'strongly disagree' to 4 = 'strongly agree'. This scale is universally used for evaluating university courses. The questionnaire items were designed to assess various aspects of the course, such as its organisation, its alignment with the course outline, its ability to inspire and engage the participants, and the effectiveness of the feedback and learning opportunities provided. In addition to the Likert scale items, the evaluation includes three short-answer questions allowing participants to express their feelings about the course. These questions ask the participants to describe the most useful aspects of the course and the reasons for their usefulness, to suggest changes to help participants learn better and the reasons for these suggestions, and to provide any additional comments. This comprehensive evaluation approach aims to capture both quantitative ratings and qualitative feedback to understand participants' experiences and identify areas for improvement.

3.3 The Teacher Development Course

The course comprised three teaching units designed to incrementally deepen teachers' understanding of introductory IoT concepts and AI data model training skills in STEM activities. They started by creating a maze in a game featuring a character on a screen controlled by a manually crafted physical joystick linked to a microprocessor. Through interacting with this system, the teachers developed a preliminary understanding of the introductory IoT concepts of sensing, reasoning, and reacting. The second unit featured a ping-pong game (Kong et al., 2024). The third unit introduced a smart face-changing game that enables users to interact with the game using a prop built with a microprocessor and a camera for AI models in classifying images. Expanding upon the previous unit's learning, the teachers gained a deeper understanding of AI model training. These processes of data model training and subsequent discussions fostered a foundational understanding of AI data model training and practical application in the development of IoT- and AI-integrated STEM activities.

At the beginning of each unit, the teachers were given an overview of the pertinent technologies and content knowledge, including TK, CK, and TCK. Subsequently, they were guided through a structured teaching process comprising the six steps: 'to play' 'to inquire,' 'to assemble,' 'to code,' 'to create', and 'to reflect'. This approach was designed to provide them with practical experience in teaching methodologies and strategies for teaching problem-solving skills and fostering digital creativity, incorporating CK, PCK, TPK, and TPACK.

In the smart face-changing unit, the teachers were initially introduced to the technological components of the project, enabling them to acquire foundational CK. Subsequently, they progressed through the six steps of the pedagogical process. At the end of the session, the teachers reflected on the IoT concepts, AI data model training, and instructional design. They also participated in collaborative idea-sharing sessions, focusing on the innovation of novel systems by leveraging their acquired knowledge, which encompassed technological components and experiences with training data models and utilising them in the STEM context. This session was crucial for fostering the teachers' digital creativity and empowering them with the skills to inspire the digital creativity of their students.

This unit provides a prime illustration of the pedagogical approach. During their interactions with the system in the 'to play' stage, the teachers (1) raised their eyebrows in front of the webcam to trigger the Mask sprite, (2) shook the fan and gold props to interact with the Gold sprite on the screen, and (3) switched between the fan and gold props in front of the webcams to control the Dress sprite and background. Figure 1 depicts how IoT concepts (sensing, reasoning, reacting) integrated with AI data model training skills in the smart face-changing system, aiding teachers in developing systems thinking.

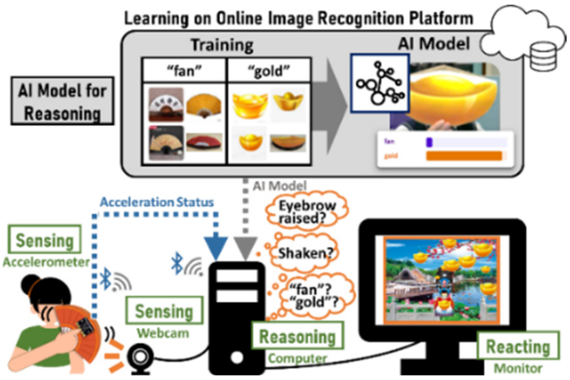

Figure 1: The IoT concepts of sensing, reasoning, and reacting with AI data model training skills in the smart face-changing system.

Subsequently, teachers then transitioned to the 'to inquire' step, examining the underlying functionality of the system through the concepts of sensing, reasoning, and reacting.

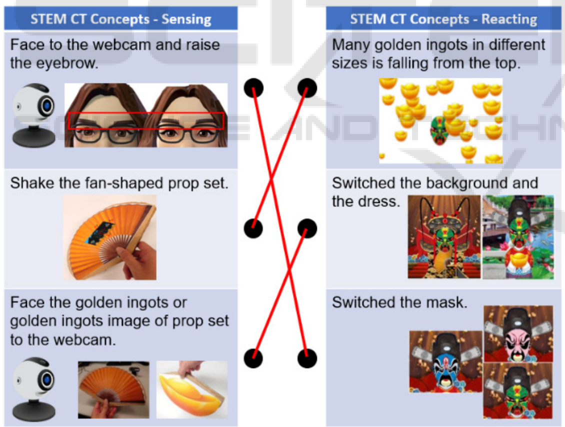

Figure 2: The worksheet designed to support students in critically reflecting on their interactions with the system.

A worksheet (Figure 2) was crafted to support the students in critically reflecting on their interactions with the system. This system comprises physical fan and gold props with a microprocessor, battery box, webcam, computer, and monitor. The built-in accelerometer of the microprocessor detects acceleration and sends data to the computer via Bluetooth. The teachers were briefed on AI confidence levels, which indicate the probability of accurate decisions, highlighting that AI decisions may not always be exact. By mapping the sensing and reacting components, students gain a nuanced understanding of how the system interprets inputs and produces corresponding outputs. This exercise is crucial for breaking down the development process into smaller, more manageable tasks, thereby enhancing students' problem-solving skills (Figure 3).

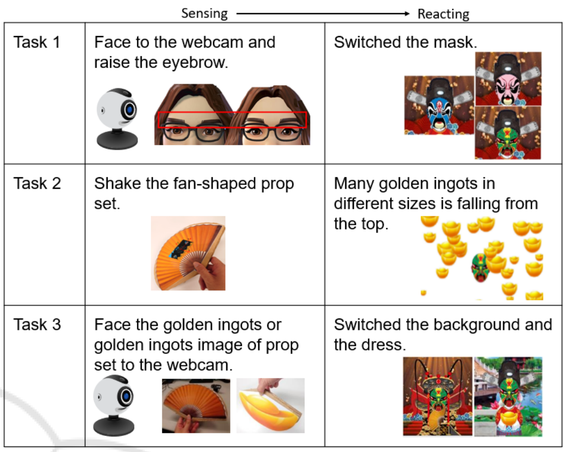

Figure 3: The decomposition of tasks.

The reflective practice incorporated into this worksheet is integral to effective instructional design, aimed at reinforcing STEM computational thinking concepts, particularly in the context of systems engineering. As students engage with this content, they will not only deepen their comprehension of the system but also develop essential skills for future projects.

Prior to the 'to assemble' and 'to code' stages, the teachers developed their abstract thinking through exploration of interactions in the smart face-changing project. They focused on (1) the pre-trained Face Sensing model, (2) the microprocessor, and (3) the data model trained using machine learning. This understanding facilitated the task breakdown of a problem into smaller tasks for incremental project development.

Task 1 integrated the 'Face Sensing' extension with the pre-trained AI data model (Figure 4).

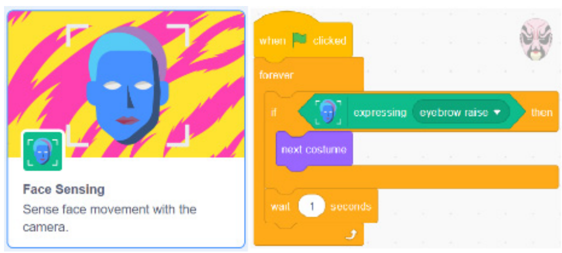

Figure 4: Using pre-trained AI data model 'Face Sensing' extension.

Task 2 focused on the steps of assembling the props (as outlined in Figure 5) and coding (Figure 6). The students had to cut cardboard according to a template provided in the appendix of the student guide. They then followed the instructions to assemble the props and install the micro:bit and battery case inside the cardboard props they created. If the assembly sequence was not followed, the props could not be built successfully. For example, if the micro:bit was not placed within the cardboard before the coloured cover was added, it could not be inserted subsequently.

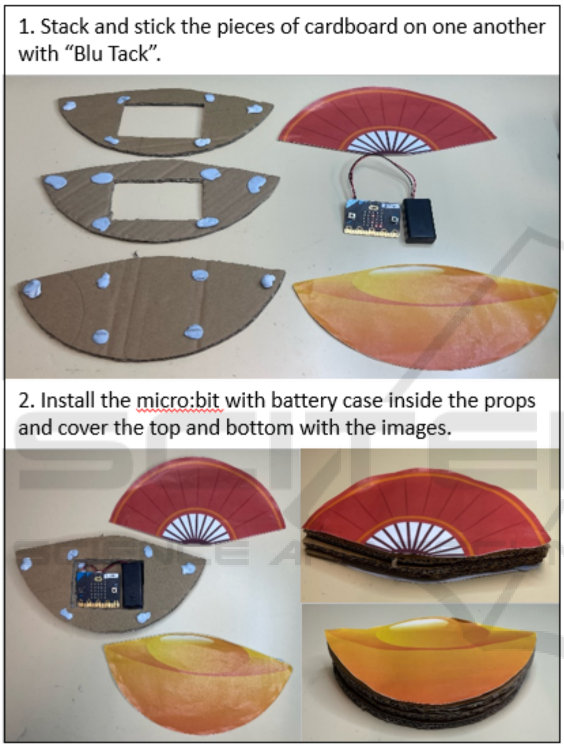

Figure 5: Prop assembly steps.

Figure 6: Blocks for controlling the Gold sprite based on the interaction with the microcontroller.

In Task 3, the teachers trained a data model to classify images as either a fan or gold. They then used the confidence levels from the AI data model on MIT RAISE Playground to control the costume changes of the Dress sprite and the background based on images captured by the webcam (see Figure 7).

Figure 7: Use of the AI data model for reasoning.

During the 'to create' activity, the teachers had to brainstorm innovative solutions for solving real-world problems. They had to explore possible AI data models, sensors, and actuators to be used to solve a new problem. Although constructing the proposed artefacts was not required, this brainstorming session enabled the teachers to apply their newly acquired knowledge from the course.

At the end of each lesson, the teachers were encouraged 'to reflect' on their learning experiences and to consider ways to enhance the pedagogy of the unit. This reflection focused on fostering their abilities in solving-problem and inspiring their students' digital creativity with digital technologies such as the IoT, AI, and physical objects. Additionally, the teachers were guided to reflect on their engineering systems thinking and to recognise that encountering and overcoming failures is an integral part of the learning process in STEM activities.

4 RESULTS AND DISCUSSIONS

4.1 Teacher's TPACK Development

A paired t-test was conducted using IBM SPSS (Version 28) on 191 pairs of pre-course and post-course survey responses to determine the significance of the changes in teachers' TPACK after completing the teacher development course. The pre-course means, post-course means, and t-test results for the individual items are presented in Table 2.

Table 2: Paired t-test results of the teacher TPACK survey, with each item scored on a 5-point Likert scale (N = 191).

	Pre		Post		
	Mean	SD	Mean	SD	t-value
CK	3.02	0.91	4.05	0.6	18.539***
TK	3.47	0.84	3.99	0.69	9.967***
PK	3.34	0.7	3.89	0.67	11.616***
PCK	3.35	0.78	3.91	0.72	10.398***
TCK	3.11	0.89	3.98	0.66	15.346***
TPK	3.07	0.91	3.94	0.71	14.299***
TPACK	3.16	0.83	3.91	0.69	13.604***
Overall	3.21	0.74	3.96	0.62	16.770***

Note. *: $p < .05$, **: $p < .01$, ***: $p <. 001$

The results indicate significant improvements across all items, with medium to large effect sizes. This suggests that the result is highly significant and that there is strong evidence against the null hypothesis. Overall, significant improvement was observed ($t(191) = 16.770$, $p < .001$), with a large effect size (Cohen's d = 1.213). For Cohen's d, a value of 0.2 indicates a small effect, 0.5 a medium effect, and 0.8 a large effect. Significant improvements were found for all of the TPACK items, with large effect sizes for CK ($t(191) = 18.539$, $p < .001$, Cohen's d = 1.341), PK ($t(191) = 11.616$, $p < .001$, Cohen's d = 0.841), TCK ($t(191) = 15.346$, $p < .001$, Cohen's d = 1.110), TPK ($t(191) = 14.299$, $p < .001$, Cohen's d = 1.035), and TPACK ($t(191) = 13.604$, $p < .001$, Cohen's d = 0.984). Medium effect sizes were observed for TK ($t(191) = 9.967$, $p < .001$, Cohen's d = 0.721) and PCK ($t(191) = 10.398$, $p < .001$, Cohen's d = 0.752).

The outcomes of the paired t-test analysis indicate a significant enhancement of teachers' confidence levels concerning the instruction of AI and IoT concepts, problem-solving proficiencies, and the cultivation of digital creativity using appropriate technological tools (TCK) because of the teacher development programme. Furthermore, the course elevated the teachers' confidence in fundamental PK, including collaborative learning techniques in STEM education, as well as TPK, which encompasses the effective utilisation of pedagogical strategies for disseminating technological information. Moreover, there was a marked improvement in the teachers' confidence in TPACK, focusing on the delivery of STEM content within the specialised framework of STEM lessons. The findings also highlight enhancements in teachers' overall TK and their capacity to apply CK to address students' learning challenges (PCK) after their participation in the course.

4.2 Evaluation of the Digital Creativity Development of the Teacher Participants

4.2.1 Analysis of the Digital Creativity Designs of the Teacher Participants

Two researchers independently assessed the teachers' digital creative evaluation, achieving high inter-rater reliability, with an ICC of 0.844 ($p < .001$) and 95% confidence intervals between 0.797 and 0.880, signifying substantial agreement. Of the 191 teachers who completed the surveys, 176 had valid submissions. Of these, 60 (34.09%) received 2 marks, 95 (53.98%) received 1 mark, and 21 (11.93%) received 0 marks. The projects were then further categorised based on the theme of the final application: 54 (30.68%) in gaming, 44 (25.00%) in health and fitness, 37 (21.02%) in teaching and learning support, 12 (6.82%) in security, 10 (5.68%) in support for learner diversity, 7 (3.98%) in smart home/campus, 4 (2.27%) in environment monitoring, 4 (2.27%) in commercial use, and 4 (2.27%) in inclusive society. Overall, 157 (82.20%) of the teachers showcased their digital creativity by designing IoT or IoT with AI systems following the development course, and 139 (72.77%) expressed their ideas about using AI.

4.2.2 Sample Designs from the Teacher Participants

In this section, we present three instances of digital creativity designs crafted by the participating teachers.

The illustration in Figure 8 was done by a teacher who devised a fitness training system aimed at categorising the type of exercise being performed by the user in front of a webcam.

In this drawing, the teacher demonstrated a profound comprehension of engineering systems thinking, clearly illustrating how individual components interact to form a complete system. The system utilises Teachable Machine to train a data model for exercise identification. Images captured by the webcam are processed by the application, which then identifies the exercise type based on the trained model. The teacher's accompanying explanation articulates the system's logic: 'If the player stand, then the sprite stops. If run correctly, then move' ['If the player stands still, then the sprite stops. If the player runs in a correct pose and timing, then the sprite also moves.'].

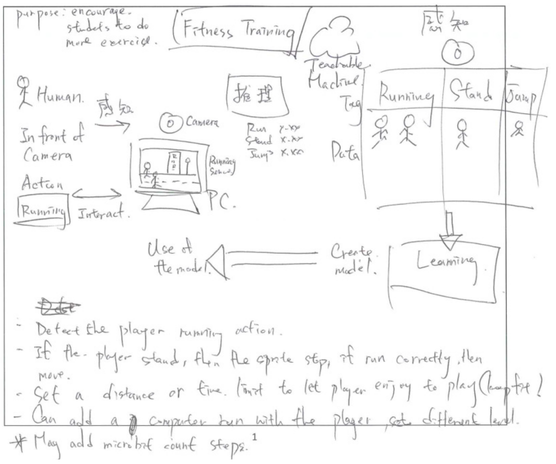

Figure 8: A teacher's conceptual design of a fitness training programme proposing the use of an AI data model to identify students' physical activity.

To enhance user engagement and promote fitness, additional features such as distance and time tracking were incorporated. The teacher wrote, 'Set a distance or time limit to let player enjoy to play (keep fit)'. Further development possibilities were also noted, including the integration of a virtual opponent: 'Can add a computer run with the player, set different level'. The teacher also suggested the addition of a step-counting microprocessor, writing, 'May add micro:bit count steps'.

Figure 9 shows another teacher's design of a similar system for fitness but with more details about its implementation. Within the realms of TK and TCK, she explicitly demonstrated her ability to select appropriate tools to underpin her concepts. This is evidenced by her strategic utilisation of (1) the pre-trained 'Body Sensing' model from Teachable Machine for exercise classification and (2) the accelerometer for tallying exercise repetitions and displaying the variety of exercises completed. Noteworthy is her adept use of variables to track the different exercise types performed and exhibit them on-screen, showcasing a sophisticated understanding of technological applications.

Her design not only underscores her proficiency in fundamental computational thinking (CT) principles such as variables but also extends into the domain of STEM CT concepts, encompassing sensing, reasoning, and reacting and the application of engineering systems thinking. The illustration not only elucidates the screen layout but also delineates the positioning and integration of the microprocessor, indicating a comprehensive grasp of technological integration and practical implementation strategies.

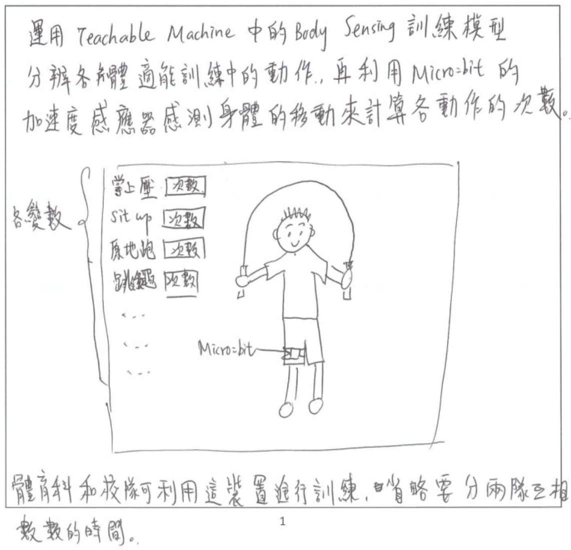

Figure 9: A teacher's design of an AI fitness training programme to identity students' physical activities with technological details.

Figure 10 shows a teacher's design of an AI energy saving system aimed at energy conservation, using a reasoning approach grounded in the AI model. The system is programmed to automatically switch off the lights and other electrical appliances when a room is unoccupied and to turn them on when the room is occupied. The teacher has effectively articulated the application of the AI model. Although the teacher mentioned that a motor would be used to control the lighting and other electrical appliances, the explanation concerning the physical control mechanisms of the lighting system was less detailed.

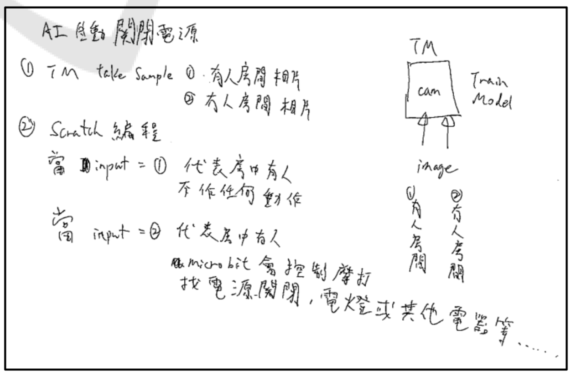

Figure 10: A teacher's design of an AI energy saving system for energy saving with proper reasoning based on the AI model.

The professional development course was designed to enhance educators' knowledge and skills in teaching STEM with IoT and AI within the framework of CT education. This study used a comprehensive evaluation methodology to thoroughly analyse the course's effectiveness and identify areas for enhancement. Building on the findings from the written and drawn artefacts produced by the teachers, as presented in section 4.2, the subsequent section (4.3) presents the findings from the analysis of their feedback in the course evaluation.

4.3 Evaluation

A course evaluation survey was conducted to gather feedback from the participants immediately following the completion of the 6-hour professional development course. This survey, which used a descriptive analysis approach, aimed to assess various aspects of the course and identify areas for improvement. The participants were asked to respond to 16 items scored on a 4-point Likert scale ranging from 1 = 'strongly disagree' to 4 = 'strongly agree' to gauge their experiences and perceptions. Additionally, three short-answer questions provided opportunities for the participants to express their feelings about the course, including the most useful aspects, suggestions for improvement, and any other comments. All 16 items are listed in Appendix II, and the results are presented in Table 3.

Table 3: Descriptive analysis results of the teacher course evaluation survey, with each item scored on a 4-point Likert scale (N = 150).

Item	Mean	SD	Item	Mean	SD
Q1	3.61	0.502	Q9	3.56	0.524
Q2	3.61	0.502	Q10	3.65	0.478
Q3	3.59	0.506	Q11	3.61	0.489
Q4	3.57	0.523	Q12	3.55	0.513
Q5	3.61	0.502	Q13	3.49	0.515
Q6	3.58	0.522	Q14	3.47	0.540
Q7	3.56	0.511	Q15	3.44	0.561
Q8	3.59	0.494	Q16	3.41	0.603

One hundred and fifty teachers completed and submitted the evaluation form after attending the teacher development workshop. The response rate was 74.63%. The sixteen items were rated between 3.41 and 3.65, and the average was 3.56, indicating that the teachers were satisfied with the quality of the course. The course was highly regarded for its organised delivery, achieving a mean score of 3.61 (SD = 0.502). The participants felt that the learning and teaching were well-aligned with the course outline, also scoring a mean of 3.61 (SD = 0.502). The course inspired the participants to think and learn, with a mean score of 3.59 (SD = 0.506). However, addressing the participants' specific learning needs scored slightly lower, 3.57 (SD = 0.523). The course effectively enhanced the participants' course-related knowledge or skills, with a mean of 3.61 (SD = 0.502). Providing appropriate feedback to enhance learning was rated 3.58 (SD = 0.522), and opportunities for learning from diverse sources scored 3.56 (SD = 0.511). Guiding participants to think from different perspectives achieved a mean score of 3.59 (SD = 0.494), and encouraging proactive engagement in learning received a mean score of 3.56 (SD = 0.524). The instructors' enthusiasm in teaching was highly appreciated, with a score of 3.65 (SD = 0.478), and the overall teaching quality was rated at 3.61 (SD = 0.489). The course's learning activities stimulated interest in teaching STEM with IoT and AI in CT education, scoring 3.55 (SD = 0.513). The course also enhanced knowledge in teaching STEM with IoT and AI and CT, scoring 3.49 (SD = 0.515), and understanding the pedagogy of TPACK, with a score of 3.47 (SD = 0.540). The participants felt that they acquired sufficient PK to teach relevant STEM CT concepts, with a mean score of 3.44 (SD = 0.561). However, confidence in teaching and developing STEM activities through Scratch programming was slightly lower, scoring a mean of 3.41 (SD = 0.603).

These results indicate that the course was received positively and was effective in enhancing the participants' knowledge and skills. However, there is room for improvement in areas such as addressing specific learning needs and building confidence in using Scratch programming for STEM activities.

Following the quantitative assessment, the teachers were asked to provide feedback on the most useful aspects of this course and their reasons.

The feedback provided by the teachers reveals a clear appreciation for various aspects of the course, primarily revolving around the integration and application of AI, hands-on activities, and teaching methodologies.

The teachers appreciated the comprehensive integration of AI in the curriculum, which enabled them to bring real-world applications into their teaching. Some of their feedback is as follows: 'What I appreciated most about this lesson was that it built upon previous Scratch activities, deepened them by incorporating AI, made it more fun, allowed us to learn more, yet remained easy to execute', 'The demo [enabled us to use] AI in our daily coding life', '[I learned] AI machine learning application', 'Theory combined with coding is very practical' and '[During the “to play” step,] Letting us to test and play the products before teaching’.

The practical elements of the course, including hands-on activities with micro:bit, Scratch, and various sensors, were particularly valued. Some of the teachers noted: ‘Having [the] opportunity to have hands on experience was beneficial’, ‘[I learned] how to use Teachable Machine in the project’, ‘Hands-on experience is useful’, and ‘The use of Teachable Machine in Scratch … is fun and not hard to use in lessons’.

The teachers also emphasised the usefulness of the pedagogical skills and methodologies imparted during the course, as these would help them deliver lessons more effectively and confidently. They said that they valued the following: ‘to play’, which allows us to get involved and draw our interests’, ‘Letting us … test and play the products before teaching’, ‘The pedagogical skills that help teachers deliver a more confident lesson. Students will benefit from the logical and systematic teaching’, ‘Giving ideas about teaching AI’, ‘Teaching us how to deliver the lessons’, and ‘Hands-on activities and handout materials’.

The development course boosted the teachers’ confidence and inspired them to use technology tools and pedagogy to deliver lessons and guide students in more interesting ways. The teachers’ feedback emphasises the importance of combining theoretical knowledge with practical applications and engaging teaching methods. Examples of the teachers’ responses with their related TPACK items are listed in Appendix III of this paper.

5 CONCLUSION AND FUTURE WORK

The findings from the teacher development course highlight significant advancements in the teachers’ TPACK, particularly in areas such as CK, TCK, and TPK. The substantial improvements across all TPACK components, with medium to large effect sizes, underscore the effectiveness of the course in enhancing the teachers’ confidence and capabilities in integrating IoT and AI into their teaching practices.

The evaluation of the digital creativity of the teacher participants further demonstrates the successful application of these technological concepts. A significant majority of teachers showcased their ability to design innovative smart systems integrating IoT and AI, reflecting a deep understanding of engineering systems thinking and the practical application of IoT and AI principles. The high inter-rater reliability in assessing these projects confirms the robustness of the evaluation process. The digital creativity evaluation provides further insight into how the teachers applied their newly acquired TK to develop TCK. The teachers demonstrated advanced technological skills and creativity in their projects, such as ideas on data model training, using pre-trained models and sensors to create interactive systems. The practical application of TK and TCK in their design artefacts highlights the significant impact of the course on their ability to adopt and adapt new technologies in educational contexts.

Additionally, the positive feedback from the teacher development workshop, with high satisfaction ratings and increased confidence reported by the participants, reinforces the value of such teacher development initiatives. The teachers expressed that the course not only boosted their TK but also inspired them to deliver lessons in more engaging and effective ways.

In conclusion, the teacher development course significantly enhanced the teachers’ competency in teaching novice IoT- and AI-integrated STEM activities and thus boosted their digital creativity. However, it was limited by a lack of evidence related to primary students or the potential changes in teachers’ confidence after real classroom practice. Future work should focus on evaluating the impact on students’ understanding and problem-solving abilities and on comparing teachers’ post-course and in-practice competencies. This will help determine the long-term effectiveness of the course in real educational settings.

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APPENDIX I

Number	Item
Q1	I understand 'sensing–reasoning–reacting' in the operation process of IoT and related concepts.
Q2	I have sufficient knowledge about STEM education in the IoT era.
Q3	I can use computational thinking practices, such as sequencing, conditional reasoning, causal reasoning, and engineering systems thinking, for problem-solving in STEM activities.
Q4	I can learn new technology easily.
Q5	I can solve technical problems when using technology.
Q6	I can adapt my teaching based upon what students currently understand or do not understand.
Q7	I usually conduct student learning activities in a collaborative way.
Q8	I can design some learning activities for students to develop problem-solving skills.
Q9	I am able and willing to provide a complete STEM activity artefact for my students to play and to inquire.
Q10	I can identify and handle what learning difficulties students might have on technological innovation in STEM education.
Q11	I understand the functions that sensors, microprocessors, and actuators perform in IoT systems.
Q12	I believe that the electronic parts of STEM teaching tools (e.g., micro:bit, M5Stick), such as sensors, microprocessors, and actuators, can be used to foster students' digital creativity.
Q13	I can use STEM tools (e.g., micro:bit, M5Stick) to organise STEM activities and foster students' digital creativity.

Q14	I can use appropriate teaching methods to teach students to inquire and understand various electronic parts (e.g., sensors, actuators) used in STEM activities.
Q15	I can teach STEM lessons that appropriately combine the content of STEM, technological innovation, and proper teaching approaches.
Q16	I can select and use technologies in my classroom that enhance what I teach, how I teach, and what students learn.
Q17	I can provide support and leadership in helping others to coordinate the use of STEM education, technological innovation, and teaching approaches at my school and/or district.

APPENDIX II

Number	Item
Q1	The course was delivered in an organised way.
Q2	The learning and teaching aligned with the course outline.
Q3	Participants were inspired to think and learn.
Q4	Participants' needs in learning were addressed.
Q5	Participants' course-related knowledge or skills were enhanced.
Q6	Appropriate feedback to enhance learning was provided.
Q7	Opportunities were provided for the participants to learn from a variety of sources or methods.
Q8	Participants were guided to think from different perspectives.
Q9	Participants were encouraged to proactively engage in their own learning.
Q10	The teacher of this course was enthusiastic about teaching
Q11	The overall teaching was of high quality.
Q12	The learning activities of the course stimulated my interest in the understanding of teaching STEM with IoT and AI (artificial intelligence) in computational thinking education.
Q13	The course enhanced my knowledge of how to teach STEM with IoT and AI (artificial intelligence) and computational thinking.
Q14	The course enhanced my knowledge of the pedagogy of TPACK in teaching STEM with IoT and AI (artificial intelligence) and computational thinking education.
Q15	I have acquired sufficient knowledge in pedagogy to teach relevant STEM computational thinking concepts, practices and perspectives.
Q16	I am confident in teaching and developing STEM activities through Scratch programming.

APPENDIX III

Selected Quotes from Teachers	TPACK
- 'Different sensing techniques were integrated into coding.'	CK
- 'The use of the data model extracted from the teachable machine and use it in an application in Scratch. It is fun and easy to implement in lessons.' - 'Showing how we can make good use of different Scratch extensions to integrate micro:bit and AI to make simple games' - 'Teaching how to play the sensor and AI. It is fun and useful.' - 'Learning [I learned] the integration of STEM, AI, and coding.'	CK, TPK, TPACK
- 'The teaching materials are abundant and can be effectively used in the classroom.' - 'Providing suitable material and hands-on practice.' - 'Learning [I learned] the use of AI data model training and knowing its impact and use in STEM activities and learn the methodology to teach students.'	TK, TPK, CK, PCK, TPACK
- '[I learned] how to use the trained data in raise MIT edu [MIT RAISE Playground platform].' - '[I learned] the use of teachable machine in Scratch. It is fun and not hard to use in lessons.' - 'Showing how to mix the usage of Scratch and micro:bit.'	TK, TPK
- 'The pedagogical skills help teachers to deliver STEM lessons with confidence. Students will benefit from the logical and systematic teaching.' - '[It] encouraged us to encourage students to create new items based on what we have learnt from the given material.' - 'It gave ideas about teaching AI.' - 'It provided teaching with examples that can be applied in the classroom.' - 'It let us test and play with the products before teaching.'	PCK