Enhance STEM Education by Integrating Product Design with Computer-Aided Design Approaches

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Abstract. In the 21st century, the innovation industries are considered as the main focus. Talents with innovation capability and creative problem-solving skills have become the greatest demand nowadays. Therefore, cultivating more diverse talents with a better education approach is essential. STEM education is the well-known creative education approach that has been adopted currently. Thus, this study provided the background of STEM education in Hong Kong, followed by identifying the problems of the current creative education. It also proposed a revolutionary education change by integrating product design and computer-aided design (CAD) education into STEM Maker education. The suggestions and recommendations of developing new learning material and lessons have been analysed for the educators. New learning material and online learning system concepts have been designed as well. The new design can satisfy the needs of the students and teachers, promoting and enhancing the current creative education by tackling the issues in each aspect.

Keywords: STEM education, Product Design, 3D Printing, Computer-Aided Design (CAD), Teaching and Learning
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1 INTRODUCTION

STEM education is the focus of attention in the 21st century. STEM stands for science, technology, engineering and mathematics. It is a knowledge-based and interdisciplinary approach that aims to promote knowledge application, enhance creative problem-solving skills, and boost students' academic performance [3],[8]. The ultimate goal is to nurture diverse talents and prepare for the future workforce in innovation industries. Recently, there is a trend that Maker education will be integrated into STEM education. Some scholars suggested that the new industrial revolution will be caused by makers [6]. Therefore, maker education is the future trend of education development that aims to cultivate students' ability to innovate. It promotes a 'learning by making' experience that focuses on how students can apply their STEM knowledge and creative thinking skills to build functional prototypes [10]. With advanced technologies, more primary and secondary school students can become makers nowadays. They are able to develop and build their models with 3D printing technology easily. Therefore, the Hong Kong Government has modified the education system of primary and secondary schools by proposing STEM education in 2015 in order to develop students' interdisciplinary thinking methods and nurture their creativity. However, two problems are identified in the research that hinder the effectiveness of STEM education in Hong Kong primary and secondary schools. Low creativity input from students and unsatisfying final learning outcomes are the major issues that need to be addressed. In light of this, integrating product design approaches and CAD into STEM education is the proposed idea in this paper for the sake of providing primary and secondary school students with a meaningful STEM learning experience. In addition, it is leading to STEM success by tackling the problems.

In the following sessions, the problems in STEM education will be identified in detail which helps to define the needs and expectations of the teachers and students in the teaching and learning process. Followed by introducing new ideas and how product design approaches and CAD can be implemented in the STEM education of primary and secondary school so as to enhance its effectiveness.

2 EXISTING PROBLEMS IN STEM EDUCATION

Literature review and first-hand research are included in the research design. Six semi-structured interviews have been conducted with teachers, primary and secondary school students in Hong Kong for the sake of clarifying their difficulties and expectations in STEM education. Students' works are also reviewed in the observation research to evaluate their STEM learning outcomes.

Low creativity input from students is the first major problem found in the current STEM education. Step by step activities will be conducted during the STEM lessons which require students to follow the manuals. Students would not be able to apply their creativity and train their practical skills [5]. The room of students' creativity input, the level of guidance of the teaching material are not well-balanced under STEM education nowadays. Although it is easier for teachers to provide assistance to all of the students in the class, students do not have chances to explore the topic by themselves since they are restricted by different instructions and guides, which means there are model answers provided. In this situation, there is no difference between each student's work since they are rebuilding the teaching model repeatedly. There is no denying that the students are able to cultivate their interest and gain a sense of accomplishment after completing the model in this teaching method. However, it is not an ideal teaching approach. There are no opportunities for them to create their own model and realise their idea in the making process. The learning and teaching material are not able to provide enough autonomy for students to explore STEM topics. For long term consideration, the effectiveness and quality of the current teaching approach will be affected since students' development in creativity and problem-solving skills are hindered.

As well as the creativity-input from students is limited, unsatisfying students' final learning outcomes are the second problems that need to be addressed. STEM education suggested learning by making experience. Students need to integrate their STEM knowledge in order to create physical prototypes by 3D printing and applying hardware. However, most of the students' final works are not completed. The students would attach all the required hardware and functional elements simply to the model without considering the organization of the component, features and appearance. In other words, the 3D printer's advantages have not been used wisely. The current STEM Maker education is unable to provide an effective learning experience for students to understand the importance of taking the good balance between visual and functional elements, and how the product is developed from zero to completed work. Under this situation, it will lead to unsatisfying STEM Maker learning outcomes.

3 APPLYING PRODUCT DESIGN APPROACHES WITH CAD IN STEM EDUCATION

This paper is proposing a revolutionary STEM education transformation by introducing the product design approach with CAD. It will be part of STEAM education. STEAM education provides a more complete package for STEM by integrating art (A) into the education. Therefore, integrating CAD and product design is the extension of STEAM education. It is more focused on designing and creating. The role of product design is not about teaching students the professional industrial and product design knowledge in detail. It aims to optimize students' learning outcomes through enlarging the rooms of creativity-input from students, suggesting the design thinking mindset, user-centred design and most importantly, providing a basic understanding about the product development process from selecting hardware to prototype making. It is a meaningful learning experience to students which enhances STEM Maker and STEAM education to a new level.

Integrating the product design concepts and CAD education are able to bring a direct and meaningful learning experience for the students to understand the whole product development process. Students can consolidate and apply their STEM knowledge to realise the function of the product, but it also provides a great opportunity for the students to learn how to develop a completed project by taking a good balance between the functional and visual elements. The students are able to experience how the products and models are designed in the CAD software before 3D printing. Hence, students can create a more refined prototype by considering the size of the hardware, the organization of the component, and the appearance design. It is a rare hands-on learning experience that requires students to apply their mathematical, engineering and design knowledge while developing the CAD model in the making process. The students are able to explore various shapes, sizes, proportions of the CAD with their imagination for the sake of making a model that have both function and appearance. They can create a completed physical product instead of sticking all the components on the model. After CAD modelling, the students' ideas can be realised through 3D printing. Their practical skills can be trained. Besides, students' design thinking skills will also be promoted which is an essential skill for them to identify the existing problems and integrate the knowledge so as to apply solutions to tackle the problem from various perspectives. Therefore, it is a new maker learning experience which does not cover under the current STEM education. It stimulates students' desire to learn. Students' learning performance, creativity, learning outcome and engagement can be enhanced because of the functional prototype with visual appeal. Their spatial ability can also be improved after experience with CAD modelling and 3D printing [1],[4]. Therefore, the proposed methods will provide a innovative learning experience for the next generation.

4 TEACHING AND LEARNING ACTIVITY PLANNING

New teaching and learning activity for primary and secondary schools needs to be developed with the new proposing teaching approach so as to address the mentioned problems, satisfy the needs of the teacher and students, and enhance the STEM Maker and STEAM teaching and learning experience. In this session, the opinions suggested by different scholars are analysed to clarify the essential factors of STEM lessons with CAD education and product design concepts. It also aims to provide recommendations for future educators to build a good quality STEM lesson plan with product design and CAD education.

4.1 Prepare Suitable Learning Material

Providing suitable and appropriate learning material for students is crucial in the lesson plan. It is important to provide opportunities for students to succeed in the learning process [2]. The knowledge and material need to be adjusted according to the level of the students. Under the new proposed framework of STEM education, most of the students are the beginners in 3D CAD modelling and they do not have the experience to design the finished product. Therefore, the teaching and learning material should not be too complicated at the beginning, which required students to create the model with advanced CAD skills [7], whereas providing students with a level-by-level learning experience is essential to learn CAD modelling and enhance their understanding in the completed design process. Thus, the students can gain a sense of accomplishment when they achieve the expected learning outcome with the appropriate learning material. Likewise, their engagement and motivation can be improved [11].

4.2 Apply Suitable CAD Software

Select proper CAD modelling software is needed for the students to learn how to build the 3D model under the new proposed educational approach. The software should be easy to use with a clear and attractive interface for the students to learn CAD modelling [7]. While they are building CAD, they are required to consider how the 3D printed components and hardware can be organized properly instead of sticking them on the 3D printed cover. Therefore, two free CAD software (*Tinkercad* and *Onshape*) are selected. They are the most suitable software for students to learn after comparing different CAD software in the market.

For *Tinkercad*, it is a CAD software created by Autodesk. It is the most appropriate software for primary students and beginner to learn CAD modelling. it is not only a free programme for teachers and students to use, but also provides a great modelling experience for them to create their own design with simple steps. Although there are no advanced commands, it requires all the fundamental tools for the beginner to realise any shapes and structures easily, which helps unlock the students' imagination.

For *Onshape*, it is cloud-based CAD software that includes different advanced features and powerful commands catering for different levels of the users to create detailed and precise 3D models. Therefore, it is the best choice for advanced learners and secondary school students.

4.3 Improve Students' Learning Motivation

Boost students' learning motivation is essential since proactive motivation and creation will enhance STEM education's teaching and learning experience. There are two major elements that can promote their motivation in the learning process. For one thing, the objective of the learning activities needs to state clearly for the students to understand how the 3D printed objects will be used and what they need to do [9],[11]. The students are able to set their aims and find their directions in the creation process. Their motivation can be improved as they know what they are going to learn and create. For another, ensuring autonomy in the learning process to provide enough room of creativity input is needed [4],[9]. Allowing students to create their own versions of design in STEM learning and CAD education are able to enhance their motivation. They are able to realise their design from CAD modelling to functional and visual appealing prototypes such that their curiosity can be activated. Trials and errors need to be encouraged in the new proposed education approaches, which enables students to explore and learn from the mistake. The students are able to apply their creative problem-solving skills and design thinking once they are facing problems. It is a great and meaningful learning experience driven by the students [4]. Their learning motivation can also be increased through developing and making their ideas.

4.4 Provide Reference and Demonstration

The completed demonstrations should be provided to students in the learning process. It is because students do not have experience in design [7]. Showing examples is an important step for beginners to learn the CAD software, understand the advantage of 3D printers, and experience the complete design process. With different demonstration examples, it helps students identify the design problems and provide clear guidance to follow and take references. Students will have a clear direction and focal point in the creation process such that they can consider the balance between visual and functional elements, and the advantages of the 3D printer can be made into good use. Besides, the students are allowed to modify and create their own design after demonstrations. Then, they are able to realise their own ideas which are different from the examples. The students can translate their imagination into a physical prototype. Thus, they will concentrate in the class with a high learning expectation on their final model outcome. Meanwhile, their creativity can be enhanced since their designs are original [9]. It also provides opportunities for students to develop their aesthetic sensibility by comparing the structure, composition, and proportion of their designs and the CAD model example. Therefore, their learning performance and outcomes can be enhanced with the demonstrations.

Furthermore, showing realistic objects and 3D printed outcomes before CAD building will help students to understand the structure and the shape of the model [2]. Their visual-spatial skills can also be improved [1],[4]. It is easier for the students to imagine their ideas in the mind and realise their own design physically in CAD software and 3D printing.

4.5 Organize Reflective Activity

Providing reflective activities is useful for students to evaluate their design solutions and learning outcome [7]. They can apply their reflective thinking skills to evaluate their learning experience. It creates an opportunity for students to understand their potentials and weaknesses. Therefore, the students are able to know their room for improvement so as to obtain a better learning result. In terms of teachers, the reflective activity can monitor the learning progress of the students and determine the students' improvement before and after the courses. Therefore, the reflective activities help teachers to facilitate teaching and enhance the learning experience in the lessons.

4.6 Hold Sharing and Performing Session

After completing the courses, holding healthy competitions, sharing and performing sessions for students are able to enhance their STEM learning outcome and motivation [2],[7]. The students will gain a great sense of accomplishment while they complete the physical and visual appealing model by applying their knowledge. Besides, conducting different sharing and performing activities provide a chance for the students to share their learning results. It is an important platform for the students to showcase their works and learn from peers. Thus, holding these performing sessions to round up their learning is essential and beneficial.

5 NEW LEARNING TOOLS AND SERVICE SYSTEM DESIGN

New learning tools and an online learning system have been designed for the proposed pedagogy, aiming to provide new learning experiences and complete package service to enhance the overall learning efficiency. Both designs are developed according to the essential educational factors mentioned in the above section. The learning tools and online learning system will be further introduced in the following section.

5.1 New Learning and Teaching Tools (Opro: 3D Printed Robot Car Design)

Opro, a 3D printed robot car design, is an innovative learning and teaching tool for the proposed pedagogy. It targets students in different learning levels in terms of product design, CAD, and STEM aspects. Students are allowed to develop their creativity on the fixed car foundation and create their own Opro design.

The preset components of the car foundation include one Arduino UNO R3 board, one L298N motor driver, one sensor shield, four TT motors, three IR infrared line follower sensors, two 18650 batteries, and one battery box (Figure 1). With these open-sourcing components, Opro allows a flexible combination of extra components and design. For instance, extra components such as cameras, ultrasonic distance sensors, infrared sensors, and led modules could be inserted onto the given car foundation, creating more learning and teaching opportunities for students and teachers, as well as empowering students to create unique functions and features on their Opro design. In short, Opro provides a higher autonomy of creativity and promotes students' self-inquiry.

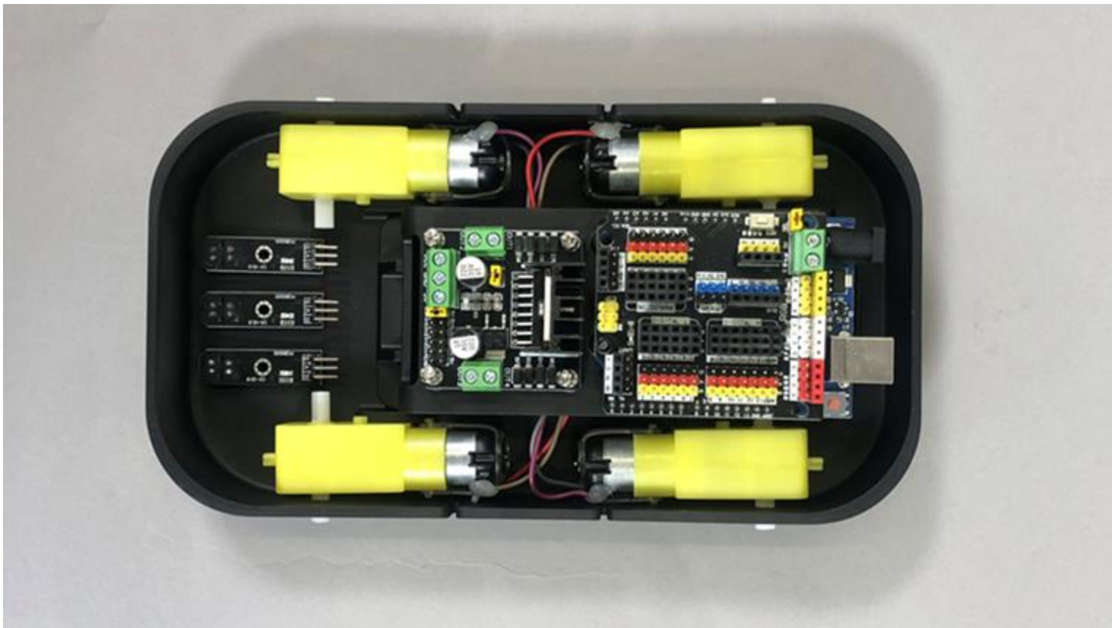


Figure 1: The preset components of the Opro car foundation.

In addition to the extendibility of components, Opro is easily affordable and open-sourced, which is favourable to all primary and secondary schools. Students can download the required learning materials so as to create their own Opro design. Besides, since Opro is Arduino-based, most of the existing visual programming editor, for instance, Scratch and Blocky, are also supported. Students who have never experienced programming can easily get started to code their Opro and realize different functions. Therefore, Opro is suitable for schools and students with different backgrounds or skill levels.

Besides, the level-based learning experience provided by Opro creates a meaningful learning experience for all types of students. Students will be classified into various learning levels and achieve different learning goals, ranging from understanding the design cycle, appearance design, and the completed product development process from selecting hardware to prototype making. Furthermore, it provides an inspiring opportunity for advanced students to create their unique dream car that can tackle daily life problems. Such an approach enlarged the room for creation and enhanced students' creative problem-solving skills and learning motivation. All in all, Opro facilitate students to create a satisfying learning outcome, meanwhile raising students' learning motivation towards STEM, CAD, moreover product design fields.

Specifically, Opro provides three learning levels, including beginner, intermediate and advanced level. Primary and secondary students are allowed to choose their appropriate learning level, enabling them to experience different design and CAD modelling processes that fit themselves the most. Thus, more refined designs that balanced both functional and visual elements could be created through the level-by-level learning approach. The detailed learning objectives will be introduced in the following section.

5.1.1 Beginner level

An Imitation learning experience is proposed for the beginner level. Figure 2(a), Figure 2(b), and Figure 3 show the suggested Opro design for the beginner level. Students are required to follow the step-by-step instructions to create the Opro, due to their unfamiliarity with CAD modelling and product design at this stage. Furthermore, guidance and tutorials will be provided for students to learn about coding, electronic knowledge, and basic operation skills of 3D modelling tools.

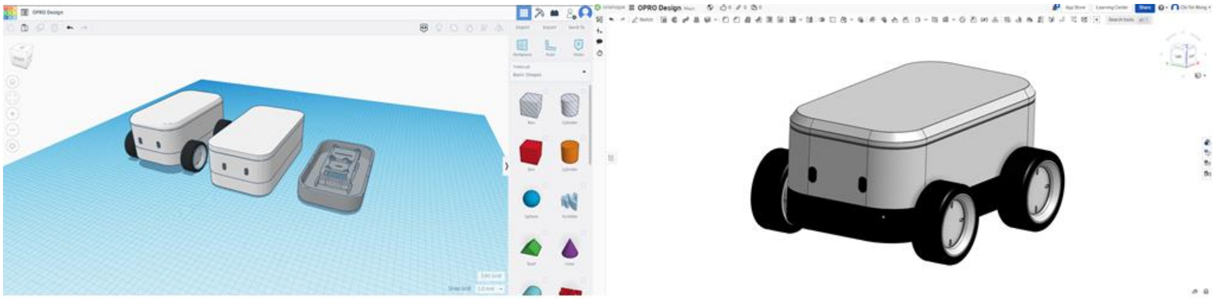


Figure 2: The CAD model of the Opro design at the beginner level: the CAD model in *Tinkercad*, and (b) the CAD model in *Onshape*.

Figure 3: A 3D printed prototype of the Opro design at the beginner level.

Throughout the learning process, the CAD model of the Opro car foundation will be provided in STL and STEP format. Figure 4(a) and Figure 4(b) show the imported model in different CAD software. For primary students with more limited CAD modelling skills, *Tinkercad* is the suggested software for importing the pre-set car base and building the Opro. Besides, students can learn how to operate the 3D modelling functions through step-by-step instructions. Thus, such an imitation learning approach could enhance learning efficiency and allows precise 3D CAD modelling.

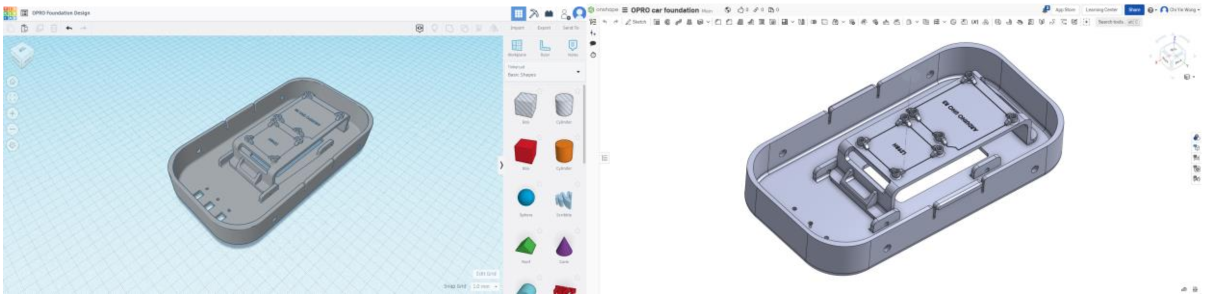


Figure 4: The CAD model of the Opro car foundation: (a) the CAD model in *Tinkercad*, and (b) the CAD model in *Onshape*.

Not only completing the CAD model and 3D-printed prototype, but numerous extra benefits are also highlighted for the beginners. For instance, assembling components in the correct position are required to finish by students (Figure 5), soft skills such as motor skills, hand-eye coordination, and special thinking skills could be enhanced. Besides, coding skills could also be trained because students have to code their Opro. In addition, Opro is a good start for students who are not familiar with 3D modelling and printing. Most importantly, the concept of 'balancing functional and visual elements' could be fostered among students through Opro.

Figure 5: The correct positioning of the components in the Opro car foundation and a 3D printed enclosure of the Opro design at the beginner level.

5.1.2 Intermediate level

At the intermediate level, appearance design will be introduced to students. Figure 6 shows the moodboard worksheet that helps students to design the enclosure. Students are allowed to select multiple images that favoured them and attach the images to the worksheet. Thus, visual elements from the selected images, such as shapes, colours and proportions, could inspire students to design the outlook of Opro. Besides, students have to consider the positioning and sizes of different hardware to build a 3D-printed enclosure that fits the car foundation. Therefore, students could experience a better application of 3D printing technology.

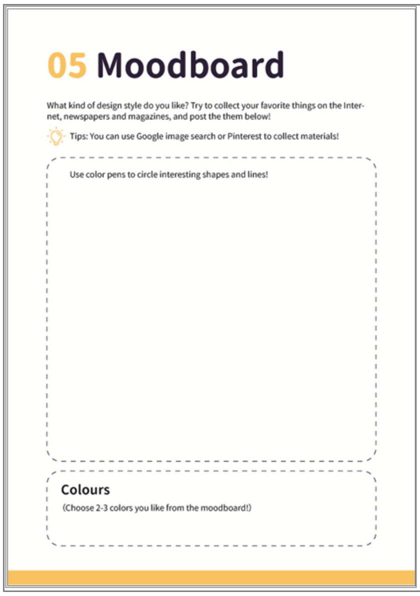
In order to better showcase the learning contents at the intermediate level, an enlightening demonstration has been designed. Figure 7 shows a completed moodboard worksheet, and Figure 8 shows the Opro design, which followed the visual language of the selected images. Students are taught to code the unique elements from the images and decode them into their unique Opro design; hence a more precise design direction could be developed.

To conclude, students' learning motivation could be enriched by the learning tasks at the intermediate level. Firstly, interest-bearing contents and topics could gain students' attention and hence enhance learning motivation. Besides, the large room of creation provided to students ensures design autonomy; students can create their dream car with the images they like. Subsequently, the interest in appearance design and CAD modelling could be enhanced.

5.1.3 Advanced Level

In terms of the advanced level, students are required to design a functional and visually appealing OPRO that able to tackle daily-life problems. Figure 9 shows a set of worksheets, including mind map, persona, empathy map, and identified problems. It assists students in creating user-centered designs that serve both functional and aesthetic purposes. With the simplified research tools given in the worksheet package, students could experience the design research process and quickly identify the user problems. Besides, design-based worksheets like moodboard will also be provided.

The worksheet set helps students list their design solutions and present their Opro design idea through sketching and CAD modelling.



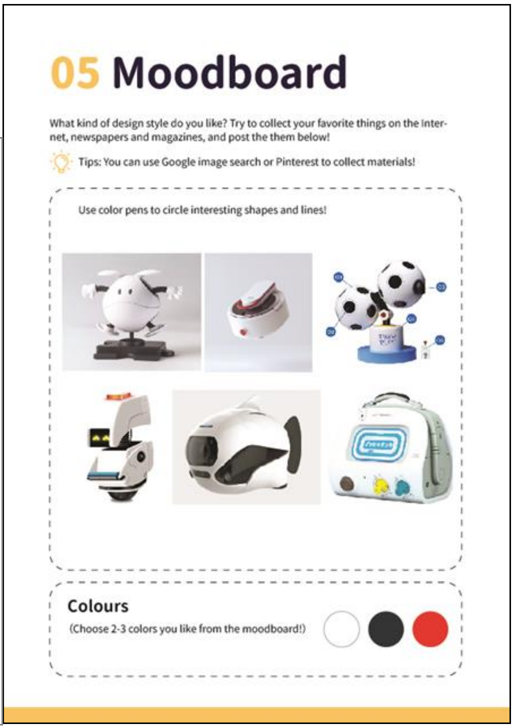


Figure 6: The moodboard worksheet. **Figure 7:** The moodboard worksheet.

Figure 8: The Opro design demonstration at intermediate level.

Moreover, a reflection worksheet is also required to be completed by students, aiming to identify their learning outcomes and room for improvement. Most importantly, teachers can understand students' learning difficulties through reflections, such that teaching methods and the difficulty could be adjusted. All in all, the worksheet package effectively facilitates teaching and learning of the Opro design.

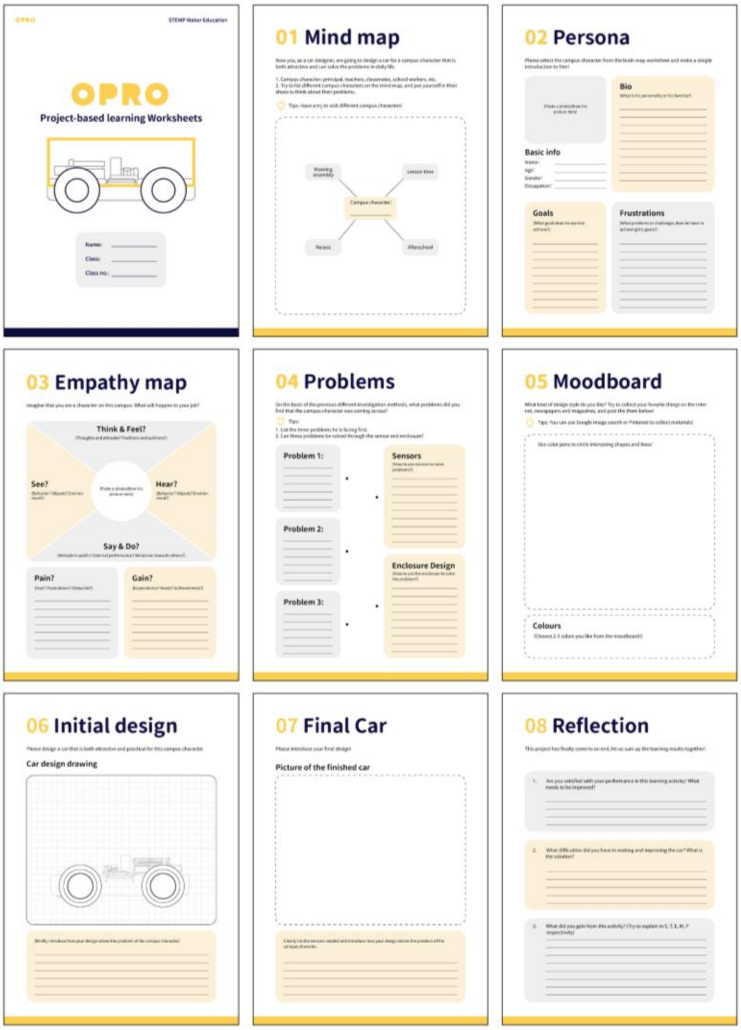


Figure 9: The worksheet set design at the advanced level.

An advanced-level worksheets sample and the corresponding Opro design have been provided to prevent misunderstandings and doubts towards the learning objectives. Figure 10 shows the completed worksheet set, and Figure 11 demonstrates the advanced-level Opro design, a campus patrol car that assists teachers' classroom management. Figure 12 shows that the exploded view of the Opro. This given demonstration could effectively enhance teachers and students' understanding in terms of teaching and learning.

5.1.4 Summary on level-based learning

The 3-level learning kits provide a valuable maker learning experience and suitable for students of any level to learn product design, CAD modelling, and STEM skills. Figure 13 has integrated the learning objectives of each stage. With the level-by-level learning experience, the students' vision in STEM learning can be extended, also enhancing learning motivation and creative problem-solving skills. Hence, the overall learning outcome of the STEM Maker project will be more completed and satisfying.

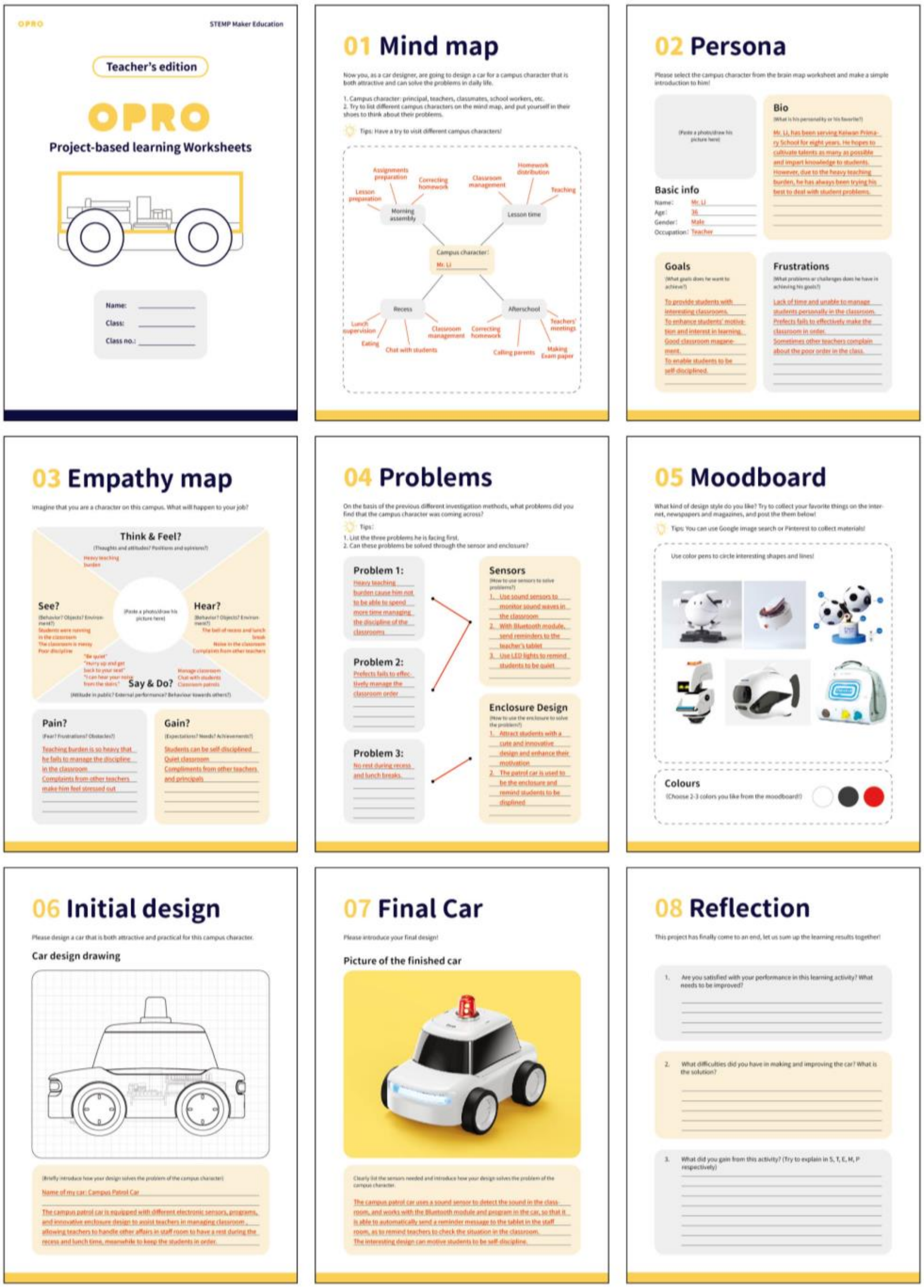


Figure 10: A completed Opro worksheet set sample.

Figure 11: A demonstration example of the Opro design at the advanced level.

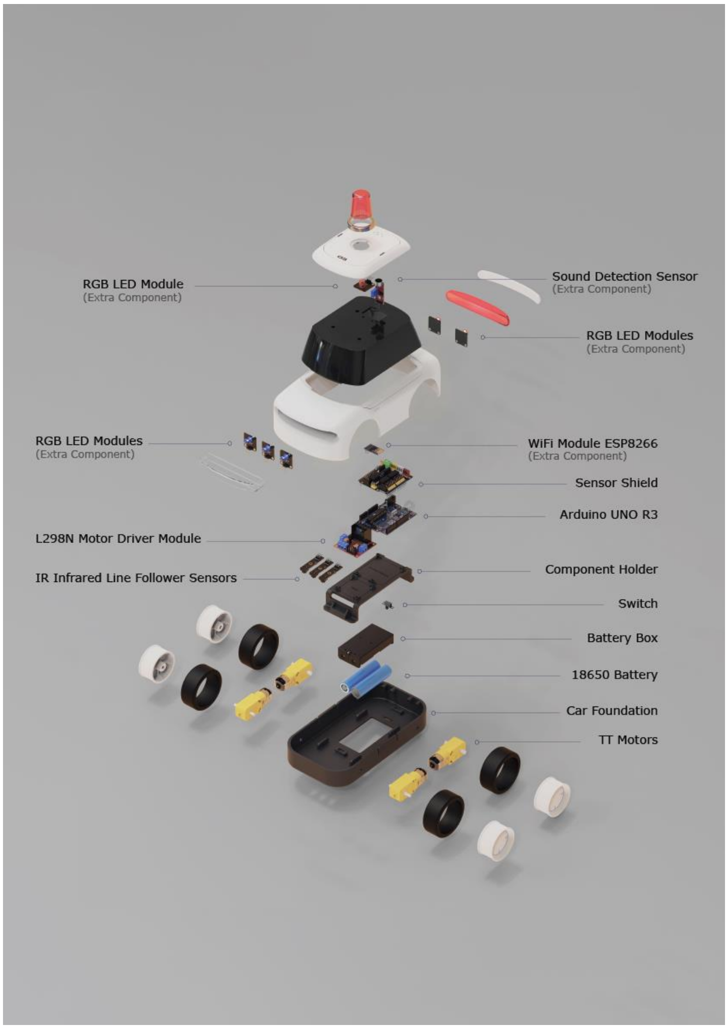


Figure 12: The exploded view of the Opro design at the advanced level.

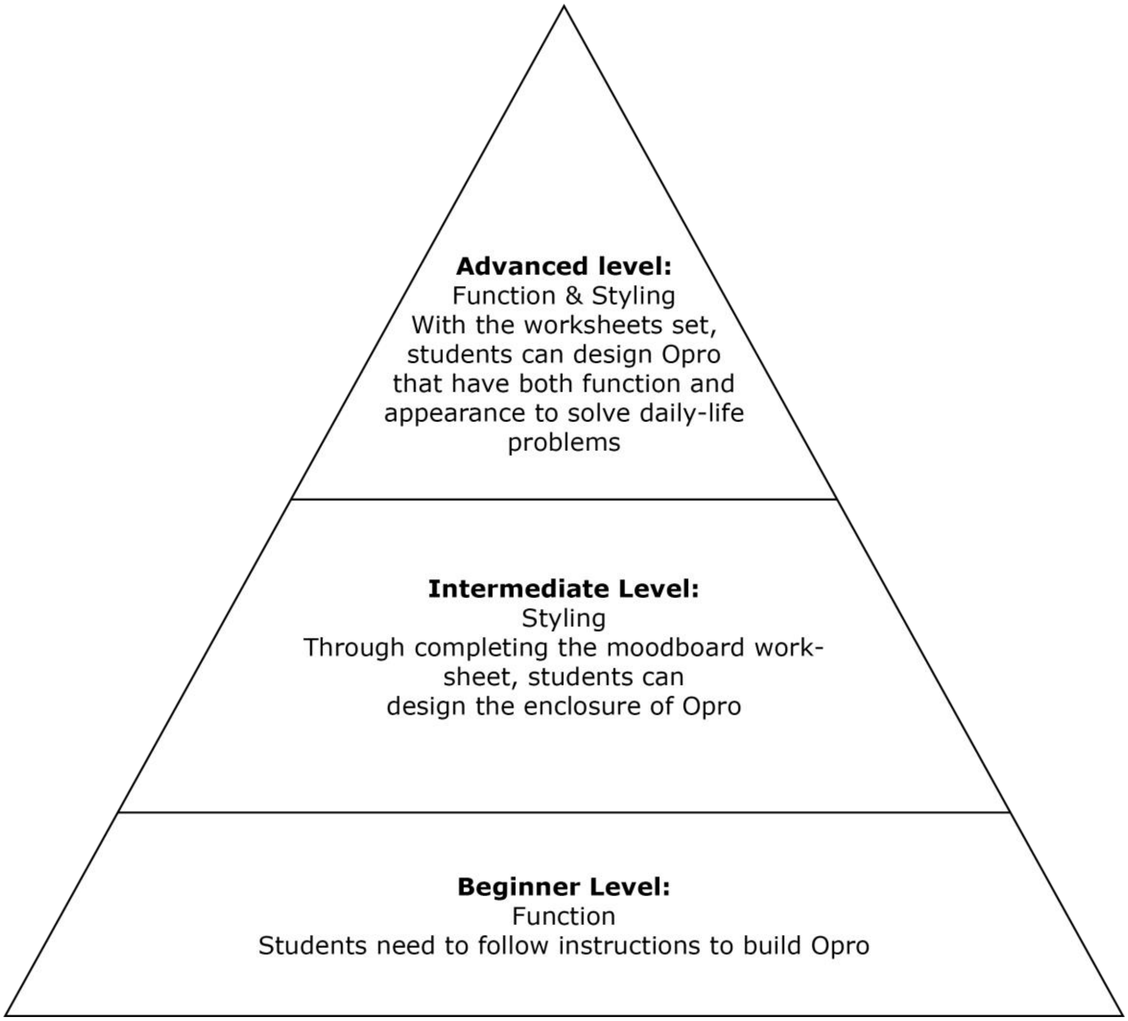


Figure 13: The learning objectives of each level.

5.2 Online Learning System Design

An online learning system concept has been proposed for this new teaching approach. It aims to provide a complete package for students and targets three main learning occasions: home, school, and interest class. Thus, four key services (online resources platform, Student Interaction Platform, 3D printer sharing service, and the online hardware store) are featured to meet the needs of different learning occasions. Figure 14 shows the website layout of the online learning system concept, and the details will be introduced in the following.

5.2.1 Online resources platform

The online resources platform is proposed to facilitate learning efficiency and effectiveness. Learning resources, for example, CAD models of the car foundation, enlightening car design demonstrations, worksheet sets, hardware information, and coding reference, will be provided to students and teachers free of charge. In short, the online resources platform provided professional materials to students and teachers and reduced teachers' load in lesson planning.

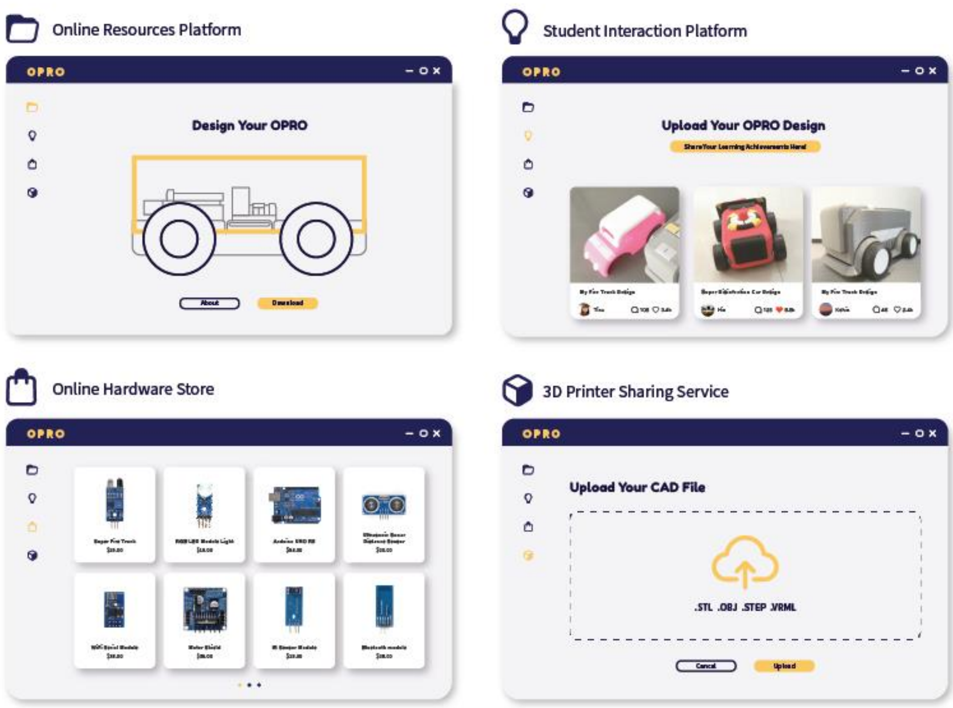


Figure 14: The website layout of the online learning system.

5.2.2 Student interaction platform

A student interaction platform is also proposed for students to share their Opro designs and learning outcomes. Students can upload the CAD files, programming codes, photos, and videos of their Opro design to the platform. They are also allowed to like and comment on peers' works. It provides an opportunity for students to gain a sense of accomplishment from others. Besides, they may get inspiration, learn from peers, understand their shortcomings, and further improve the design through online interactions on the platform. Hence, the platform could help to promote a healthy learning environment and enhance the quality of students' learning outcomes.

5.2.3 3D printer sharing service

The online learning system also features a 3D printer sharing service, which aims to resolve equipment limitations on different learning occasions and reduce the burdens of 3D printers at school. The lack of learning facilities could possibly limit students' design and prototyping process, leading to an unsatisfactory learning outcome and even hindering learning motivation. In light of this, the proposing 3D printer sharing service cooperates with 3D printing companies, allowing students and teachers to print their CAD files at a low cost. The service also allows a broader selection of printing materials and methods than traditional printers at schools. Therefore, the 3D printer sharing service provides a more convenient prototyping experience for all students to realize their designs, as well as release the burden of limiting facilities at schools.

5.2.4 Online hardware store

Lastly, the online hardware store allows teachers and students to consume sensors and 3D hardware whenever and wherever possible. The complete package service allows students to buy the component directly on the website conveniently. In addition, the consumed hardware will be delivered to their home or schools, such that the extra time cost of consuming sensors outside school is reduced, and students may test and refine their designs more efficiently. Thus, the overall learning flow and prototyping efficiency could be effectively enhanced.

5.2.5 User flow of the online learning system

Figure 15 shows a complete user flow of the online learning system. The advanced level is taken as an example for better understanding.

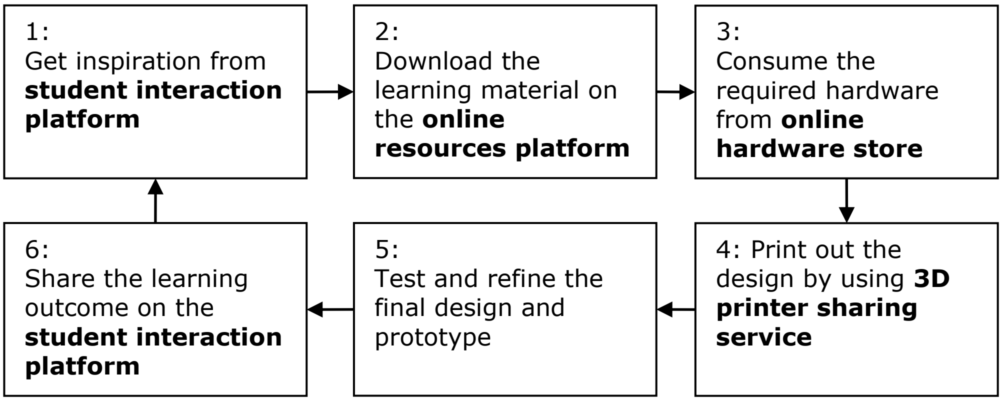


Figure 15: The user flow of the online learning system.

5.2.6 Summary of the online learning system

The overall online learning system provides a one-stop package service to teachers and students, simplifying the entire learning process and enhancing prototyping efficiency. Moreover, the STEM learning outcomes and students' learning motivation could also be enhanced.

6 PILOT TEACHING

A one-week advanced level pilot teaching has been conducted as a user test, to evaluate the effectiveness of the OPRO design and the new proposed education framework (Figure 16). Throughout the pilot teaching, the entire design cycle process, ranging from user research, ideas brainstorming, CAD modelling, and prototyping, was experienced by a primary 6 student. Also, *Onshape* is being adopted as the suggested 3D CAD modelling software throughout the pilot teaching. Eventually, an OPRO that can disinfect and clean the floor was designed and created by the participant, meanwhile balanced both functionality and visual attractiveness.

Figure 16: The participant's design process.

6.1 Feedback and Effectiveness

For the purpose of evaluating the effectiveness of this pedagogy, the reflection worksheet was provided to the participant, and the generally positive feedback has proven that OPRO is beneficial to students in terms of user-centered design and appearance design.

6.2 Autonomy and Satisfaction

Firstly, OPRO enhances students' autonomy and sense of satisfaction. Figure 17 shows that the participant revealed that students' design autonomy is hindered in the usual curriculum. Meanwhile, it is satisfying to design an Opro that can solve problems. There is no doubt that OPRO ensures the room for creation and provides students with a sense of achievement.

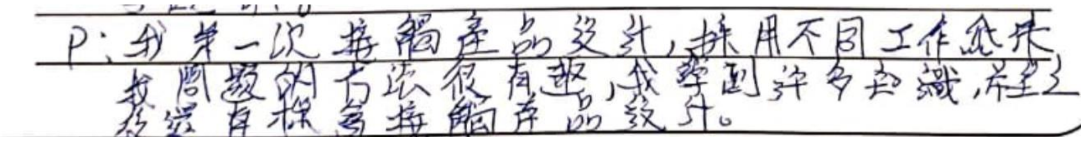

T:這是我第三次使用3D打印機，平常的課程根本不讓我設計自己喜愛的東西。我很開心這一次可以創作自己喜歡的小車。

English translation:
"I am not allowed to design stuff I like in usual lessons…"
"I am satisfied with designing my own OPRO and able to help with her difficulties."

Figure 17: Feedback regarding learning satisfaction and autonomy.

6.3 Balancing Functional and Visual Elements

Besides, the worksheets are beneficial in teaching the concept of "balancing functional and visual elements." Figure 18 shows that the participant expressed his interest in identifying problems, as well as learning appearance design with the worksheet sets. It has proven that OPRO effectively provides a great learning experience for students to create a user-centered and attractive appearance design.

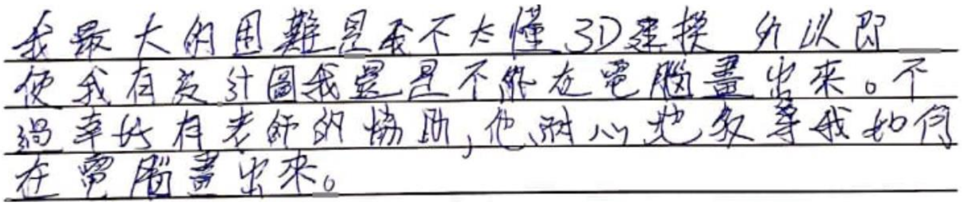

P:我第一次接觸產品設計，採用不同工作紙來找問題的方法很有趣，我學到許多知識，希望之後還有機會接觸產品設計。

English translation:
"It is my first time exposed to the product design field, and it is fun to use different worksheets to identify problems."

Figure 18: Feedback regarding the concept of balancing functional and visual element.

6.4 CAD Modelling and Learning Motivation

Furthermore, positive feedback regarding CAD modelling is also received. For instance, the CAD modelling practice provided by OPRO, which is not covered in the current curriculum design, enhanced the participant's spatial thinking skills. Most importantly, the participant stated that OPRO enriched his curiosity towards CAD modelling and achieved a sense of accomplishment (Figure 19). However, issues regarding CAD modelling were revealed throughout pilot teaching. The participant mentioned that it is challenging to build CAD models without teachers' assistance. Moreover, the unfamiliarity of *Onshape* hinders students' modelling skills. However, it is believed that students' self-practice could resolve the mentioned issue. Thus, it could be concluded that OPRO is beneficial for students to enrich their curiosity and skill set in terms of CAD modelling.


我最大的困難是我不太懂3D建模，所以即使我有設計圖我還是不能在電腦畫出來。不過幸好有老師的協助，他耐心地教導我如何在電腦畫出來。

English translation:
"My biggest challenge is that I am not familiar with 3D modelling, such that I was not able to draw it in 3D software even though I had the design sketch with me."

Figure 19: Feedback regarding CAD modelling and learning motivation.

6.5 Summary on the Effectiveness of Opro

All in all, the precious feedback from the pilot teaching has proven that the OPRO teaching kit design is effective in enhancing students' design autonomy and interest in CAD. Also, Opro is advantageous in teaching the concept of "balancing functional and visual elements" and user-centered design.

7 INITIAL PLAN OF IMPLATATION

The pilot teaching has proven that the proposed pedagogy is advantageous in enhancing students' STEM skillset and interest in CAD modelling and product design. To benefit more students and popularize the creativity education approach, an initial plan has been developed to implement the proposed pedagogy.

Three primary schools and three secondary schools in Hong Kong will be invited as trial points in the beginning stage, respectively. Meanwhile, feedback from students and teachers will be collected and analysed to further evaluate the scheme's effectiveness. Furthermore, STEM and product design experts from different sectors will also be invited to classroom observation. Their feedback will also be collected to ameliorate the teaching approach and the proposed OPRO educational kits.

To diffusely implement the proposed pedagogy among all primary and secondary schools in Hong Kong, not only the proposed online learning system is inevitable, but also the follow-up work. Regular workshops will be conducted among different schools to promote OPRO, for instance, CAD modelling workshops for students and teachers, as well as joint school competitions, to complement excellent OPRO design among the participating students. Also, product design students from universities could be invited as student mentors to share their design experiences and enhance students' motivation towards the design industry.

All in all, popularizing the proposed pedagogy among Hong Kong primary and secondary schools is the key focus of the initial plan of implementation. Students could benefit from this creative education approach regarding STEM skillset and the interest in CAD modelling and product design.

8 CONCLUSIONS

In this paper, the existing problems in current STEM education identified from desktop research and first-hand research had been discussed. Hence, integrating product design concepts and CAD education into STEM education could enhance the teaching and learning experience in the lessons and allow students to experience a completed maker design process, from selecting hardware to CAD modelling and 3D printing.

Furthermore, the teaching activity guidelines are also provided. The six essential elements and suggestions have been analysed to develop the learning material and lesson planning in the new educational approach, aiming to promote a more effective and meaningful learning experience to enhance students' interest in innovations.

The new pedagogy has been proposed in response to the above problems and insights, and the respective learning tools and an online learning system have been developed. The new learning tool Opro, which is a 3D printed robot car design, provides a 3-level learning experience. It enlarges the room of creation of the students, allowing students to consider the organization of the hardware and visual elements, also make good use of 3D printing technology. The design cycle, research tools, user-centered design, and appearance design are also featured to expand students' thinking mindset; thus, the ideas and prototypes created by students can be well-developed.

Apart from the new learning material design, an online learning system has been designed to provide a complete package service to students. It facilitates the new proposed education approach. Further studies are needed to evaluate the proposed STEM educational approaches and design. The goal is to provide a well-rounded learning experience and training for the next generation to cope with the future trend of innovation industries.

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