Title:
Using Product Design Approaches with Computer-Aided Design to Enhance STEM Education.

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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 would be integrated into STEM education. Some scholars suggested that the new industrial revolution would 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 printers easily. Therefore, The Hong Kong Government have modified the education system by proposing STEM education in 2015 in order to develop students' interdisciplinary thinking method 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 computer-aided design (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. It is leading to STEM success by tackling the problems.

In the following sessions, the problems in STEM education would 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.

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 outcome.

Low creativity input from students is the first major problem found in the current STEM education. Step by step activities would 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 and instructions 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. 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 following the steps and finish the model with this teaching method. However, it is not an ideal teaching approach. There are no opportunities for them to create their own model and realize 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 would 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 and products in the learning process 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 on 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 would lead to unsatisfying STEM Maker learning outcomes.

Applying Product Design Approaches with CAD in STEM Education:

This paper is proposing a revolutionary STEM Maker education transformation by introducing the product design approach with CAD. It would be part of STEAM education. STEAM education provides a more completed package for STEM by integrating art (A) into the education. Therefore, in my approach, integrating CAD and product design is the extension of STEAM education. It is more focus 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 centered design and most importantly, providing a basic understanding about the product development process from selecting hardware and CAD modelling to 3D printing. It provides a meaningful learning experience to students and enhances STEM Maker and STEAM education to a new level.

Integrating the product design concepts and CAD education are able to bring a direct learning experience for the students to understand the whole product development process. Not only students can consolidate and apply their STEM knowledge to realise the function of the product, but also it provides a great opportunity for the students to learn how to develop a completed project through taking a good balance between the functionality and visual elements. The students are able to experience how the products and models are designed in the CAD software before 3D printing. The students can create a more refined prototype by considering the size of the hardware, the organization and the position of the component, and the appearance of the outlook design. It is a rare hands-on learning experience which 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 taking a good balance between the functional and visual elements of the model. They can create a completed physical product instead of sticking all the components on the model. After CAD modelling, the students' ideas can be realized through 3D printing. Their practical skills can be trained. Besides, students' design thinking skills would also be promoted. It is an important skill for students to identify the existing problems and integrate the knowledge so as to apply solutions to tackle the problem from different perspectives. Thus, the students can integrate their knowledge from different sources and aspects of STEM education to tackle the problems in the creation process. 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 CAD modelling and 3D printing [1],[4]. Therefore, the proposed methods would provide a meaningful learning experience for the next generation.

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 and STEAM teaching and learning experience. In this session, the opinions suggested by different scholars are analyzed 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.

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, share the awareness of visual elements, 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].

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 comparison with 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 to learn CAD modelling. Not only it is a free programme for teachers and students to use, but also it 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 realize any shapes and structures in an easy way which helps to unlock the students' imagination.

For Onshape, it is cloud-based CAD software which includes different advanced features and powerful command catering for different levels of the users to create detailed and precise 3D models. It would be the best choice for advanced learner and secondary school students. It is because their absorbing ability are higher. Therefore, Onshape would be easy for them to operate and create their CAD model.

Improve students' learning motivation

Boost students' learning motivation is essential since proactive motivation and creation would enhance the teaching and learning experience of STEM education. Thus, 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 would 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 realize 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.

Provide reference and demonstration
The completed demonstrations should be provided to students in the teaching 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. It is an imitation learning which helps students to identify the design problems and provide clear guidance for them to follow and take references. Students would have a clear direction and focal point in the creation process such that they can consider the balance between visual and functional elements. The advantages of the 3D printer and resources can be made into good use. They would concentrate in the class with a high learning expectation on their final model outcome. Besides, the students are allowed to modify and create their own design after demonstrations. Worksheets also need to be provided to guide students to design in a correct direction, for example, the worksheet can be a design moodboard for students to get inspiration of form and shape. Then, they are able to realize their own ideas which are different from the examples. The students can translate their imagination into a physical prototype. Thus, 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 also 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 realize their own design physically in CAD software and 3D printing.

Organize reflective activity
Providing reflective activities is useful for students to evaluate their design solutions and identify the problems of their models [7]. The students are able to know where and how they need to improve in order to obtain a better design outcome. They can apply their reflective thinking skills and problem-solving skills in order to tackle the problems. It also ensured the students would not go off the track and topic of the learning activities. In terms of teachers, they 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.

Hold sharing and performing session
After completing the courses, holding healthy competitions, sharing and performance sessions for students are able to enhance their STEM learning outcome and motivation [2],[7]. The students would gain a great sense of accomplishment while they can complete the physical and visual appealing model by applying their knowledge. Conducting different sharing and performing activities would provide a chance for the students to share their learning result. It is an important platform for the students to showcase their works and learn from each other. Their learning motivation and interest would be increased towards the future STEM courses.

Conclusions:
In this paper, the existing problems in current STEM education of Hong Kong primary and secondary schools have been reviewed which includes the desktop research and first-hand research. Hence, integrating product design concepts and CAD education into STEM education is the proposed concepts

which are able to enhance the teaching and learning experience in the lessons. It also improves the education system by enlarging the framework, it provides students with a better understanding of the completed design process. It is important to deliver a maker experience for the students to create the whole ideas on their own, from selecting hardware to CAD modelling and 3D printing. They are able to make good use of 3D printing technology such that the students can consider the organization of the hardware and visual elements while they are building CAD. The design thinking skills would also be introduced for the students to expand their thinking mindset. As a result, the ideas and prototypes created by students can be well-developed which facilitate STEM development. Furthermore, the teaching activity guidelines are also provided. Six important elements and suggestions have been analysed for the educators to develop the learning material and lesson planning in the new educational approach. It aims to promote a more effective and meaningful learning experience for students to enhance their interest in innovations. The detailed teaching and learning material designs have been introduced in the full paper and is currently being reviewed by Computer-Aided Design and Applications. Further studies are needed to evaluate the proposed STEM educational approaches. 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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