Journal of Engineering Science and Technology
Special Issue on i-CITE 2018, November (2018) 27 - 34

ENGAGING STUDENTS IN USING 3D PRINTING TECHNOLOGY TO ENHANCE COGNITIVE STRUCTURES AND THOUGHT PROCESSES RELEVANT TO ENGINEERING DESIGN

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Abstract

We investigated the thought processes and cognitive structures of senior high-school students and first-year engineering college students with respect to 3D printing-based robotic insect design. First, we conducted a teaching experiment, followed by in-depth interviews, flow-maps and meta-listening activities, to assess the students' thought processes and cognitive structures with respect to engineering design. This paper presents and discusses the results of this study and the findings can serve as a reference for the future design, development and implementation of related curricula.

Keywords: 3D printing, Cognition structure, Engineering design, Thought process.

1. Introduction

The engineering education sector has gradually focused more on the question of how to improve the engineering student retention rate since the publication of The Engineer of 2020 [1]. The National Science Foundation stated that the completion rate for bachelor's degrees in engineering has decreased in the past 20 years [2]. One major reason why gifted students are less likely to choose engineering-related institutions, apart from the various false impressions that the engineering field usually presents [3], could be because of their insufficient knowledge of these institutions, resulted in the unwillingness to enter an engineering-related field. According to Brophy et al. [4], assisting students in acquiring basic engineering literacy at the K-12 level is an important factor in addressing the lack of talent in engineering. Recently, strengthening education in science, technology, engineering, and mathematics (STEM) fields has been recognized as an important issue for increasing the economic power and competitiveness worldwide [5].

Based on studies by Raju and Clayson [6], STEM education currently more focuses on science and mathematics and the important roles of technology and engineering seem to be disregarded. Actually, engineering is important as science and mathematics and knowledge alone is of no consequence to the future of life if it does not manifest itself into material significance through engineering design. Appropriate implementation of engineering education should be a topic of great significance for the K-12 level students. Hence, the twelve-year compulsory education law was passed in Taiwan recently. The curriculum guidelines of technology education will emphasize on assisting students in acquiring basic engineering literacy in addressing the lack of talent in engineering and the focus has tended to be on the engineering design process, as many studies suggested [7].

Another feature of the 12-year compulsory education law that affects the technology curriculum is the use of digital manufacturing tools to complete engineering design projects. As stated by Blikstein et al. and Lipson and Kurman [8, 9], the educational value of digital manufacturing tools, such as 3D printing, stems from their efficacy in enabling students to visualize dynamic virtual objects and produce tangible models, thereby allowing them to represent abstract concepts. Moreover, 3D printing could also help students to acquire procedural knowledge through modelling, and by learning how to apply scientific and design principles to solve problems. Thus, 3D printing can be incorporated into education via the development of an engineering design curriculum aiding students in the synthesis of theories and ideas related to design, output, and revision processes [3].

Accordingly, the aim of this study is to develop a 3D printing engineering design curriculum to enhance the cognitive structures and thought processes related to the engineering design of high school students. The engineering curriculum contains exploratory and preparatory elements to bridge the gap between high school education and university-level engineering design courses [6]. Thus, it is important to identify differences in competency and cognitive structures between high school and college students in the context of the 3D printing engineering design curriculum. The outcomes of this study will contribute to the design and development of future curricula utilizing digital learning technology.

2. Methods

2.1. Participants

A 12th grade class from a senior high-school (24 students) and first-year engineering college students (36 students) were invited to participate in our 3D printing engineering design curriculum.

2.2. Curriculum development

As stated by Atman et al. [10], an engineering design process was used to develop the robotic insect design curriculum and the hands-on activity. The planning of the curriculum involved preparing teaching materials, planning and formulating lessons, preparing the required materials, and arranging equipment and implementation procedures. The curriculum and teaching activity lasted eight weeks, with two 50-minute classes per week for a total of 800 minutes. The robotic insect design activity used a combination of 3D-printed and laser-cut parts, Arduino microcontrollers and sensor modules, and dual DC motors to create the robotic insects. Each robotic insect can be controlled through a simple joystick phone app and can handle various types of terrain, based on its design.

- Week one: Students were shown videos of various robots to stimulate their interest in the activity. The goals of the hands-on activities were discussed, and handouts were distributed. The handouts were used to review the students' acquired knowledge pertaining to this 3D-printing engineering design project.
- Week two and three: Students were divided into sub-groups. Each group was provided with modular materials that allowed them to obtain a preliminary understanding of robot structures and to code in Arduino.
- Week four: Students were instructed to collect data, develop concepts, and design the wheel and the form of their robot on the handout.
- Week five and six: Students were taught how to apply the data collected in Week 4, and their accrued knowledge, to complete their designs. Teachers and students discussed the feasibility of the designs.
- Week seven: Various materials and 3D printers were used to complete prototypes and the designs were evaluated and revised.
- Week eight: Students presented their designs and entered their robots into an obstacle course race. Students then reviewed their performance and provided feedback on the handout.

2.3. Data collection and analysis

In-depth interviews, flow-maps [11], and meta-listening [12] activities were used to explore potentially effective ways of using 3D printing technology to develop students' thinking and cognitive structures as they pertain to engineering design and to assess the overall performance of the students in this context. The interview questions [13] included: (1) How did you apply engineering-related thought processes to the design of your robot? (2) Please elaborate on the concepts you have just mentioned. (3) Please explain the relationships between the concepts you discussed. and (4) Is there anything else you would like to add?

Audio interview files were transcribed into text and the concepts delineated by the students were represented as flow-maps in the sequence that they described. If the students described additional concepts during the meta-listening phase, these new concepts were inserted in sequence. If they changed their descriptions, the original statements were amended accordingly. The main concepts discussed by each student were listed in chronological order and interconnected via arrows. If a concept mentioned by the interviewee was related to a previous concept, the concepts were connected via reciprocal linkage. Four aspects, extent, correctness, integration, and availability [12], informed the assessment of the students' engineering design-related thought processes and cognitive structures, Table 1 defines these four aspects.

Table 1. Analytical framework of cognitive structures.

Aspect	Definition
Extent	Initial and final number of linear linkages
Correctness	Proportion of incorrect conceptions
Integration	Initial and final number of recurrent linkages, initial and final complexity of linear concepts
Availability	Number of changes in linear concepts and recurrent linkages, and changes in the complexity of linear concepts

3. Results

Figure 1 illustrates the 3D printing models created by the senior high-school students and Fig. 2 illustrates the models of the first-year engineering college students.

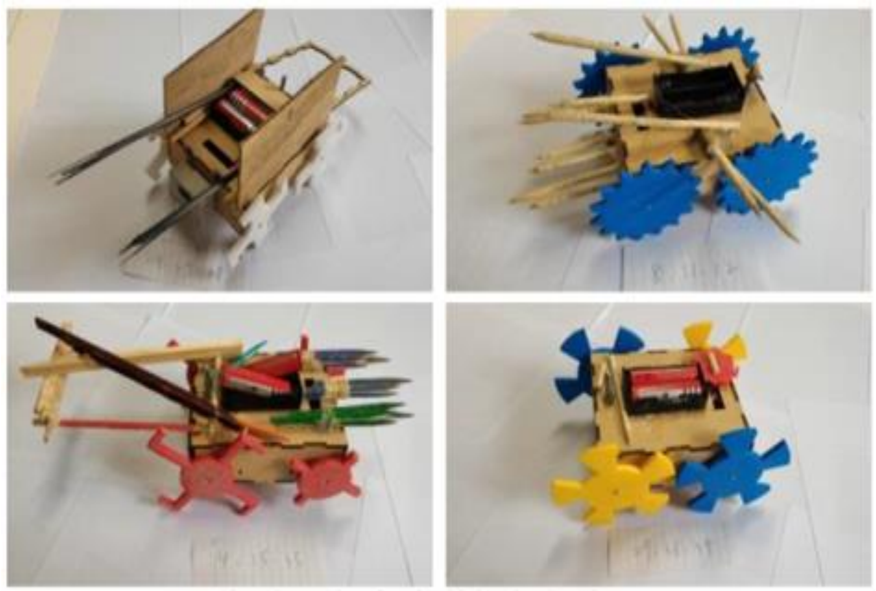

Fig. 1. Models of senior high-school students.

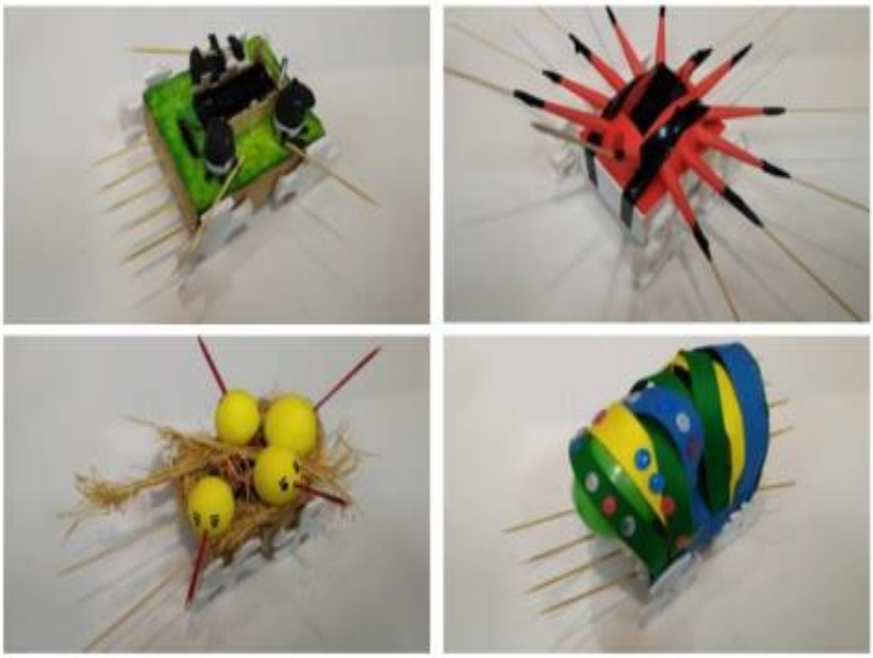

Fig. 2. Models of first-year engineering college students.

Two flow-maps depicting cognitive structures, based on one randomly selected senior high-school student and one randomly selected first-year engineering college student, were compared in this study and are illustrated in Figs. 3 and 4, respectively.

Table 2 compares the cognitive structures of one senior high-school student and one first-year engineering college student.

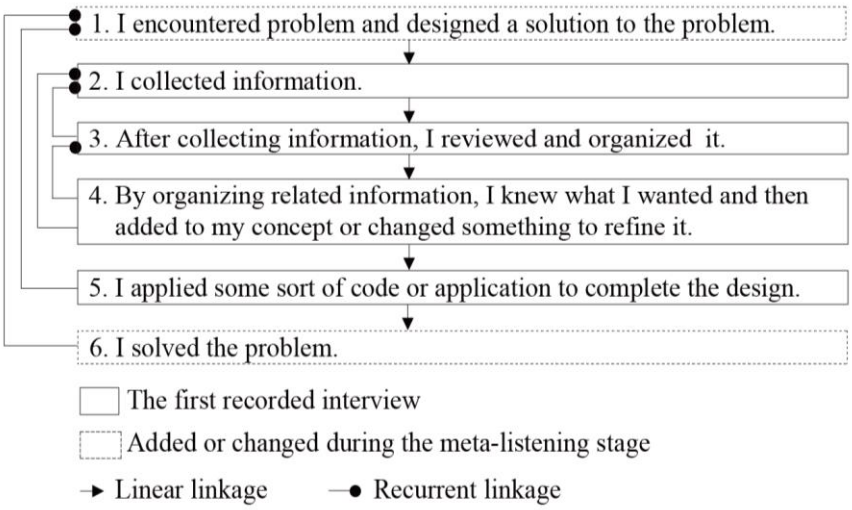

Fig. 3. Flow-map of cognitive structures of a senior high-school student.

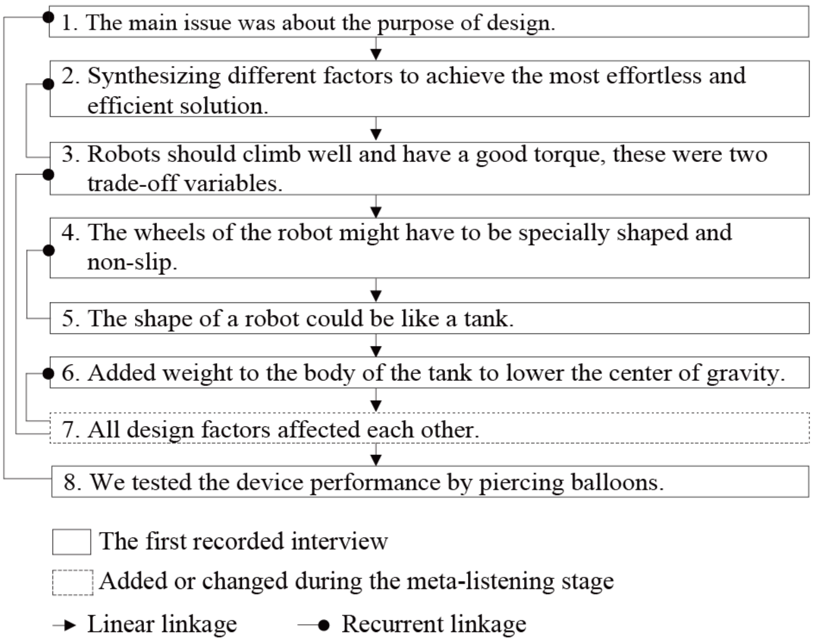

Fig. 4. Flow-map of cognitive structures of an engineering college student.

Table 2. Results of cognitive structures of two different education level students.

Cognitive structure element	Frequency	
	Senior high-school student	First-year engineering college student
Extent		
Initial number of linear linkages	4	6
Final number of linear linkages	5	7
Correctness		
Number of incorrect conceptions	0	0
Integration		
Initial number of recurrent linkages	3	3
Final number of recurrent linkages	4	5
Initial complexity of linear concepts	□□□□	• .34
Final complexity of linear concepts	□□□□	□□□□
Availability		
Change in linear concepts	1	1
Change in recurrent concepts	1	2
Change in complexity of linear concepts	0.01	0.08

4. Discussion and Conclusions

As expected, the models of the first-year engineering students were superior, and more diverse, than those of the senior high-school students. Based on studies by Atman et al. [10], the senior high-school students obviously had minimal experience in 3D modelling, as noted in previous studies. The senior high-school students were not equipped to create complex models or detailed model processes. In contrast, the first-year engineering college students were proficient in 3D modelling and were therefore comfortable with the design process. Our 3D printing technology could serve as a practical tool to help students create more creative and complex models.

Following the experimental teaching activity, in-depth interviews and meta-listening activities were used to generate flow-maps based on the experiences of one representative senior high-school student and one representative first-year engineering college student. These maps were then analysed in terms of their extent, correctness, integration, and availability of the concepts [12]. As can be seen in Table 2, however, there was little variation between the two students in these aspects. The senior high-school student's flow-map shows that 6 of 10 concepts were mentioned during the in-depth interview ("identification of a need", "problem definition", "gathering information", "generating ideas", "modelling", and "implementation"). The concepts of "feasibility analysis", "evaluation", "decision-making", and "communication" were not discussed. The flow-map of the first-year engineering college student also reveals that 6 of 10 concepts were mentioned in the interview ("identification of a need", "problem definition", "generating ideas", "modelling", "feasibility analysis", and "evaluation"). The concepts of "gathering information", "decision-making", "communication", and "implementation" were not discussed. Both students omitted the concepts of "decision making" and "communication".

The first-year engineering college student did not discuss more concepts than the senior high-school student. According to Moore et al. [14], the 3D printing technique helped the students develop a higher-order understanding of important concepts but not to assist them in attaining more comprehensive thought processes when it came to engineering design.

This study aimed to combine 3D printing and engineering design processes within a single curriculum, and investigated the effects of the curriculum on high school and college students with the aim of highlighting differences in knowledge and skills between the two groups, ultimately to improve curriculum development. The results of this study could serve as a reference for the design of future 3D printing engineering design-related curricula.

In terms of the limitations of this study, the analyses were based on qualitative data, i.e., information extrapolated from written accounts. This method might not have been suitable for capturing all of the students' engineering design-related thought processes and cognitive structures, where the students might have presented their thoughts in summary format because of the greater effort involved in writing versus oral dissemination. Although we asked the students to express their ideas in as much detail as possible before they completed the questionnaire, this limitation may still have affected the results.

Acknowledgement

The authors gratefully acknowledge the financial support provided by the Taiwan Ministry of Science and Technology under Project MOST 104-2511-S-003-040-MY3.

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