A Study on the Effect of Digital Fabrication in Social Studies Education

Development of a Self-Learning Program for Creating 3D Educational Materials and Teaching Practice

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***Abstract*—One of the learning methods that is increasingly being practiced in primary and secondary education is inquiry-based learning. This is not just a class to teach knowledge, but to practice activities to search for and discern the significance and essence of things. In social studies education, various trials and errors are being conducted, such as learning local history through fieldwork, and new approaches suitable for inquiry-based learning are being sought. In this study, as a new approach to social studies education, we developed a self-learning program that enables teachers to create original 3D educational materials using digital fabrication technology. We conducted an experiment in which students who wished to become social studies teachers participated in the program, created 3D educational materials, and taught a class using the materials. As a result, all the subjects who took the self-learning program could create 3D educational materials and give classes using them. The subjects' opinions suggested that practicing classes using 3D educational materials is effective for teacher education. This contributes to STEAM education, which has been spreading recently in the field of education, and this case study can be seen as a novel model.**

***Keywords*—Digital fabrication; 3D educational materials; self-learning Program; social studies; STEAM education**

I. Introduction

In Japan, 3D printers are being promoted as school equipment in secondary education, making the use of 3D printers in school education more realistic. Usui et al. [1] report that the Ministry of Education, Culture, Sports, Science and Technology of Japan has added descriptions of 3D printers to its guidelines for developing educational materials for junior high schools and that 3D printer are now included in the curriculum guidelines for junior high-school technology and home economics courses and senior high school art, information, and industrial arts courses. There are already examples of 3D printers in science and technology education classes. Kurita et al. [2] use 3D topography created with a 3D printer as an aid in science classes to get an overview of the terrain, and they conduct classes that include on-site observation and fieldwork. Kadota et al. [3] incorporated the use of 3D CAD and 3D printers in a technology class to develop a radio-controlled car using a microcomputer, allowing students to learn multiple contents. Then, Muramatsu et al. [4] practiced and tested a learning curriculum for students in a teacher training program for technology courses to build a model for introducing digital fabrication into school education. These precedents are probably due in part to the fact that digital fabrication is well matched to the content of these subjects.

However, the use of 3D printers in the classroom has been limited to a few subjects, and there are few practical examples, especially in social studies. This is probably because social studies teachers are far removed from technologies such as 3D printers and cannot imagine using them in social studies classes. Even if a 3D printer is close at hand, the opportunities that are not used well will limit the scope of inquiry-based learning.

In this study, we will develop a program that can practice digital fabrication, including 3D printers, in social studies education. It is a self-learning program that enables even beginners to create educational materials with a 3D printer and practice teaching with 3D educational materials. After class practice, we examine whether 3D educational materials are effective for social studies.

II. Program Description

A. Previous Work

In developing the content to be used in this study, the teaching methods in e-learning in CAD were considered. Ahmed et al. [5] implemented a method for undergraduate students to demonstrate 3D modeling in an architectural 3D CAD class. As a result, students' motivation to learn and class understanding improved. Bodein et al. [6] indicated that in their survey of e-learning in CAD, they differentiated three types of instructional methods: awareness training (how to use the software), full training (how to operate the various functions), and performance support. In this study, we used teaching-by-demonstration and learning differentiated into steps.

B. Identification of the Teaching Content for beginner by Interview

The purpose of this program is to assist beginners in creating educational materials in history and geography through self-learning. We interviewed three teachers who teach digital fabrication to get an idea of the content needed for beginners. All teachers have over eight years of experience teaching 3D CAD modeling and digital fabrication using 3D printers, CNC Milling Machine, etc. In the interview, we asked them to specify what beginners find difficult in the way of 3D model creation and digital fabrication. Furthermore, we found that beginners had difficulties when installing the software, so we made the program learnable from this point on.

C. Skills Required for Creating 3D Educational Materials and Self-Learning Program Contents

We identified the items required for the self-learning program. The content was designed so that beginners can learn step by step. Table I shows the skills needed to create 3D educational materials as a self-learning program. The process of creating 3D educational materials is divided into three steps, with each process consisting of detailed steps.

D. Selection of Contents of Social Studies Class

An example of a classroom practice studied in this program is the influence of topography on Japanese history. The 3D educational materials created by this program are modeled using a 3D printer with 3D topographic data provided by the Geospatial Information Authority of Japan (GSI) [7]. For more effective use of 3D educational materials, they can be used along with other educational materials.

E. Creation of Self-Learning Program

This self-learning program is built as a web system consisting of videos and an e-textbook. It consists of two parts. One is a method for creating 3D teaching materials composed mainly of videos, and the other is a classroom case study composed mainly of images and text. The 3D modeling software used was Fusion360 by Autodesk, Inc. [8].

Fig. 1 shows the screen where the 3D CAD operation method is explained. The instructor indicates the points to pay attention to in the voice while operating the software.

TABLE I. SELF-LEANING PROGRAM CONTENTS FOR CREATING 3D EDUCATIONAL MATERIALS

Item No.	Step No.	Contents
1.What is 3D CAD and how to install it	1	What is 3D?
	2	What 3DCAD can do
	3	How to install 3DCAD and initial setup
2. 3D CAD Exercises	1	How to use key command operations
	2	2D sketching
	3	Geometric constraints
	4	3D modeling (Parametric modeling)
	5	Conversion to manufacturing data format
3. Features and Usage of Digital Machines	1	What is Digital Fab?
	2	Types of 3D printers and features of modeling
	3	Use 3D printer
	4	Features of CNC Milling Machines
	5	Use CNC milling machine
	6	Which machine to choose?

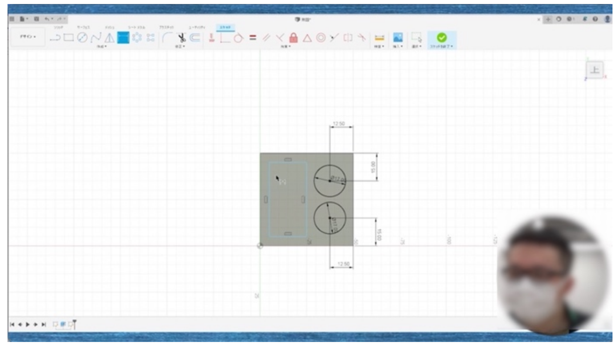

Fig. 1. An example of a self-learning program screen when explaining the operation of 3D CAD..

Fig. 2 shows an example of a class using 3D educational materials. The professor of social studies education explains key issues regarding specific classroom practices using 3D educational materials. The 3D educational materials created for the class are described with images and a written description of how to put them into practice.

Fig. 2. An Example of an Explanation of Key Issues in a Class using 3D Educational Materials.

Fig. 3 shows a mock class using 3D educational materials. The content is structured so that it can be implemented in class time.

Fig. 3. An Example of a Class using 3D Educational Materials.

III. EXPERIMENT

The following experiment was conducted over a total of eight weeks.

A. Self-Learning Program for Creating 3D Educational Materials

1) Overview of experiment: In this experiment, we asked subjects to take all the contents of the self-learning program in the correct order, up to the point where they completed the 3D educational materials. We investigated whether the subjects could produce 3D educational materials without any problems after attending this program. After the experiment, subjects were asked the questions shown in Table II.

TABLE II. QUESTIONNAIRE FOR SELF-LEARNING PROGRAM FOR CREATING 3D EDUCATIONAL MATERIALS

Question	**Level（1/2/3/4/5）**
Q1. Were the self-learning program easy to understand?	**1 – not at all 5 – very much**
Q2. Were the speed of the explanation of the 3D CAD operation by video adequate?	**1 – not at all 5 – very much**
Q3. Were the content of the self-learning program sufficient for you to operate the 3D CAD?	**1 – not at all 5 – very much**
Q4. Did you find it stressful to understand the content of the self-learning program?	**1 – very much 5 – not at all**
Q5. If you were doing new class content, would you use a self-learning program like this one?	**1 – not at all 5 – very much**

2) Subjects: The subjects of this program are 20-year-old students: three males and three females, who aspire to become social studies teachers. Their PC skills are limited to daily use of Office software (Word, Excel, PowerPoint), and this is their first experience using specialized software such as 3DCAD.

3) Experimental conditions: Subjects took a self-learning program using their PCs. From the software installation to 3D data creation, the subjects used their PCs, and 3D educational materials were created at the Makers Floor (a fab facility equipped with 3D printers, CNC milling machines, and other digital fabrication equipment) located at Tamagawa University.

Fig. 4 shows the Form 2 [9]（Formlabs Inc.） 3D printer used in this study, which uses SLA printing: stereolithography, in which resin is cured by laser exposure for modeling. The software PreForm[10]（Formlabs Inc.） was used to convert 3D data (STL) to modeling data. The material used was Grey Resin. Fig. 5 shows an example of 3D educational materials. Fig. 6 shows the MDX-40A[11]（Roland DG Corporation） CNC-milling machine used in this study. The software SRP Player [12]（Roland DG Corporation）was used to convert 3D data (STL) to modeling data. The material used was chemical wood (SANMODUR MS-E). Fig. 7 shows an example of 3D educational material produced by a CNC milling machine.

Fig. 4. 3D Printer “Form 2 (Formlabs Inc.)”.

Fig. 5. An Example of 3D Educational Materials Modeled by 3D Printer.

Fig. 6. CNC Milling Machine “MDX – 40A (Roland DG Corporation).

Fig. 7. An Example of 3D Educational Materials Modeled by CNC Milling Machine.

B. Self-Learning Program for Teaching Practice in Social Studies Classes

1) Overview of experiment: Subjects first took the entire "Teaching Practice in Social Studies Classes" part of the self-learning program using their PCs. Then, each subject set their theme and reviewed the 3D educational materials they wanted to use in that class. Since the self-study program was also a collection of examples of classes using 3D educational materials, the subjects referred to it as needed when considering the content of their classes. After the experiment, subjects were asked the questions shown in Table III.

TABLE III. QUESTIONNAIRE FOR SELF-LEARNING PROGRAM FOR TEACHING PRACTICE IN SOCIAL STUDIES CLASSES

Question	Level（1/2/3/4/5）
Q1. Were the self-learning program easy to understand?	**1 – not at all 5 – very much**
Q2. Were the speed of the explanation of the 3D CAD operation by video adequate?	**1 – not at all 5 – very much**
Q3. Were the content sufficient for you to understand the significance of using 3D educational materials in your classroom?	**1 – not at all 5 – very much**
Q4. Have you been fully briefed on how to plan for implementing 3D educational materials in your classroom?	**1 – not at all 5 – very much**
Q5. If you were doing new class content, would you use a self-learning program like this one?	**1 – not at all 5 – very much**

2) Subjects: The subjects of this program are 20-year-old students: three males and three females, who aspire to become social studies teachers. These are the same subjects who attended the self-learning program for creating 3D educational materials.

3) Experimental conditions: After attending a self-study program on how to create 3D educational materials, the participants created and re-created 3D educational materials and discussed class content and class development over six weeks. After that, a mock class using 3D educational materials was conducted.

IV. RESULTS

All the subjects (n = 6) who took the self-learning program could create 3D educational materials and could practice teaching a mock social studies class for junior high school students using the 3D educational materials. Each experiment was conducted using questionnaires and interviews. The averages for each question are shown in Fig. 8 and Fig. 9. The results indicated high average values for both programs.

A. Self-Learning Program for Creating 3D Educational Materials

The results show that most subjects learned without stress and felt a slight deficiency in the amount of instructional content. Additionally, the following statements were made in the free response section of the questionnaire.

- After the experience, I felt a sense of joy and accomplishment when I created it came to me.
- I was relieved to find that with the self-learning program, creating 3D educational materials was easier than I had expected, even for someone like me who is not excellent with ICT.
- I could create the product by myself because I was carefully taught how to install the software and how to create the product using 3D CAD.
- I used to think that making things was something you did with your hands, but after the course, I learned that there is more than one way to make things.
- Using 3DCAD, I could create teaching materials like a game like Minecraft and produce them right in front of my eyes. This was especially interesting and fun for me.
- Although this program is for teachers, I thought it would be more accessible if there was a format that would allow children to experience it as well.

B. Self-Learning Program for Teaching Practice in Social Studies Classes

The results show that all items have high values, with easy-to-understand explanations rated especially high. Additionally, the following statements were made in the free response section of the questionnaire.

- I felt the significance of the advancement of technology and its use.
- I thought it was the knowledge I needed to know as a teacher.
- I created a 3D topography. I felt that the advantage of 3D topography is that it provides a bird's-eye view of the area through the senses of sight and touch.
- I thought the creator of 3D educational materials needs to understand the characteristics of what he or she wants to create and output it.
- I thought that a great deal of knowledge about 3D educational materials is needed both in terms of hardware at schools and among teachers themselves so that they can be used as educational materials in many schools in the future.

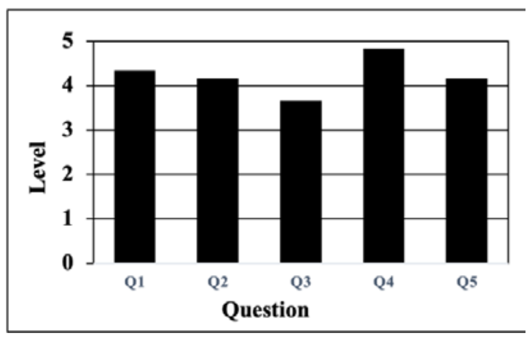

Fig. 8. Average Levels of Questionnire Results of Self-Learning Program for Creating 3D Educational Materials.

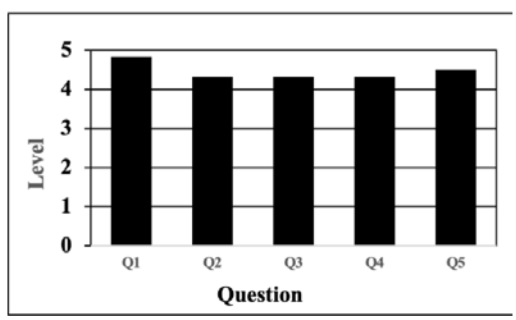

Fig. 9. Average Levels of Questionnire Results of Self-Learning Program for Teaching Practice in Social Studies Classes.

V. Discussion

A. Potential of Digital Fabrication in Social Studies Education

As a result of the self-learning program, first, the purpose of creating 3D educational materials was generally achieved; all the subjects completed the 3D educational materials, although there were a few who experienced difficulties in operating the 3D CAD system. This indicates that even beginners can create 3D educational materials if they follow the appropriate instructions since the program deals with technical content.

However, there are issues regarding the practice of teaching with 3D educational materials. Excerpts from the actual evaluation comments are provided below.

- The content of what to create as 3D educational materials could not be decided.
- The lack of practical examples makes it difficult to realize in class and limits the scope of the concept.
- Without the support of social studies discipline-based epistemological approach, it is difficult to know what to express using 3D educational materials.

Many comments on classroom practice were about the implications of the class, such as what kind of 3D educational materials should be created and how to develop a class based on them.

However, many commented that they were deeply interested in the practice of teaching with 3D educational materials and wanted to practice it more. Participants who completed lessons using 3D topography using data provided by the Geospatial Information Authority of Japan showed great interest in the possibilities offered by these 3D educational materials.

These results indicate that the self-learning program developed in this study is effective in providing technological support, while improvements are needed in areas related to the "teacher's discipline-based epistemological approach" in classroom practice using 3D educational materials.

B. Effectiveness of using 3D Educational Materials in Social Studies Education as Teacher Education

Consideration of the opinions of the subjects of the self-learning program suggests that to be able to create 3D educational materials optimized for inquiry-based learning and implement them in their classes, teachers themselves must be able to articulate "what they want to communicate to their students." For example, if a teacher wants to teach students about the geography of an area, "What kind of terrain can be created to highlight its features?" or "Will the students be able to notice the natural principles themselves?" ... etc., the teacher will have to deeply consider such questions, determine their perspective, set the task, and question their background knowledge. Additionally, empathy will be needed to imagine from the student's perspective.

Thus, the creation of 3D educational materials optimized for inquiry-based learning is beneficial not only for the teacher's reflection but also for the acquisition of one's perspective and the formation of a new view of teaching that emphasizes a discipline-based epistemological approach. The self-learning program developed in this study will also enable teachers to create their tailor-made teaching materials, thereby realizing a learning environment that is optimized for everyone.

C. Toward a Novel STEAM Education

After considering the results of the self-learning program and the process of implementation, we considered that the process for teachers to create effective 3D educational materials can be explained by the following new model, which includes design thinking in STEAM education. Fig. 10 shows the novel model. This is tentatively called the Hamada - Hirakoso model.

First, let us explain from outside the model illustration: we believe that the seeds of ideas for creating 3D educational materials are many across broad humanities. This means that the range of ideas itself would be limited if there is no intellectual activity such as consciously ingesting knowledge regularly.

However, knowledge is not enough to generate ideas. It is necessary to have one's perspective. This perspective can be viewed as an art of teaching. In this model, "one's perspective" and “sense of values” is “Art”. It is only when one's perspective is established that one can decide what kind of educational material should be created, and having multiple perspectives allows one to consider various possibilities at the same time.

And the ability to access STEM expertise must create educational materials. This can be paraphrased as "the ability to implement. This ability of implementation is “Design thinking”. The five steps of the process described in Design Thinking, “Empathy”, “Define”, “Ideate”, “Prototype”, and “Test”, are used to link the seed of an idea to a solid basis. Additionally, through a process of trial and error, we searched for better educational materials. Without this process, good educational materials will never be completed. Design thinking will be used to access STEM, create educational materials, and implement classroom practices. We believe that teachers can use this model as a map for their daily practice.

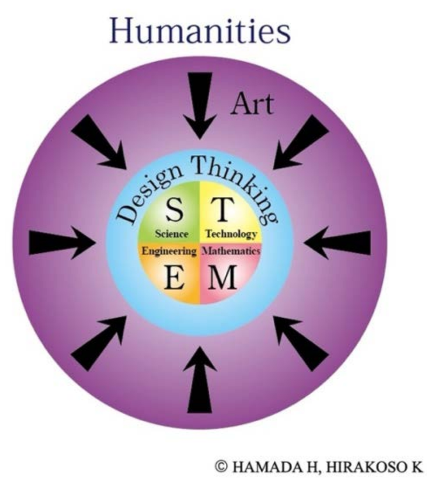

Fig. 10. A Novel Model of STEAM Education.

VI. Conclusion

In this study, we developed a self-learning program that enables students to practice digital fabrication, including modeling with a 3D printer, in social studies education.

In the experiment, subjects who were beginners in digital fabrication could create their own original 3D educational materials after taking this self-learning program. After considering the opinions of the participants in the self-learning program, creating 3D educational materials and teaching with 3D educational materials is a test of a teacher's ability. In other words, the results suggest that creating original 3D educational materials is effective for teacher education. This could be considered a novel model for STEAM education.

In the future, we intend to brush up on the program and expand the number of users by creating many examples of this program in practice. We would also like to verify whether the novel model we discovered was versatile enough.

Acknowledgment

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