Consideration of Digital Transformation of Laboratory Training Sessions and Proposal of Course Design Approaches

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Abstract

In an attempt to effectively introduce DX into a laboratory training course, this paper divided course topics into knowledge and practical skills, examined them from the perspectives of taxonomy, motivation, and self-efficacy, identified some issues inherent in the current training sessions, and made some suggestions for improvement. With these suggestions for improvement in mind, we presented an example of how to create a digital aid that provides enactive mastery performance and verbal persuasion to students. An interview/questionnaire survey conducted on several students revealed our digital aid to be useful for self-directed learning. This digital aid can be used for imagery rehearsal to prepare for the upcoming session, and those students reaching a certain level of preparedness quickly can proceed to the on-site practical training sooner than those who have not reached that level, which can help disperse the number of participants present in the room at a particular point in time, as compared to the conventional scheme where all students simultaneously proceeded to on-site practical training. Dispersion of students would be effective for controlling the spread of viruses, which is in fact one of the objectives of offering this digital aid.

Keywords: DX, Taxonomy, Motivation, self-efficacy, digital aid

1. Introduction

A laboratory training course for students studying science, engineering, and design in higher education institutions such as universities is an important subject that enables students to acquire both knowledge and practical skills. This course requires students to actually work in a laboratory to manipulate devices and tools and process substances and reagents (hereafter collectively referred to as "materials"). Practical skills can be defined as the ability to perceive the changing state of materials through the manipulation of devices and tools by using the body, and use the perceived information (sometimes in combination with inferences and predictions) to ensure proper evaluation and manipulation. Most educators agree that training sessions should be provided in a laboratory because "manipulation" and "perception" are mandatory.

One way to enhance the learning experience in a laboratory training course is to introduce digital transformation (DX) into the class (Aulakh et al., 2020; Garcia-Morales et al., 2021). DX in this context can be defined as something that runs on a computer that can heighten learning efficiency by changing the entire learning steps (including the actual laboratory sessions) and learning methods, which can be achieved by incorporating digital aids (e.g., videos, pictures, voice, texts, chatbot, etc.) and learning procedures into preparation (preparation for the upcoming session) and review (review of the previous session).

This paper proposes how to design digital aids (including multimedia and Web features) and how to motivate students to learn in a laboratory training course. We use the Revised Taxonomy (hereafter, "the taxonomy") (Anderson et al., 2001) as a guide to designing digital aids. We also draw on the psychology of learning to consider ways to motivate students to learn. Although the taxonomy sets out learning goals, it does not describe how to improve the levels of achievement of each goal. This presents us with the need to introduce a concept that helps students improve the achievement levels. Motivating students to improve their achievement levels requires proper guidance based on a psychological approach. In view of this, we adopted Bandura's self-efficacy (Bandura et al., 1997; Kelley et al., 2020), which is one of the motivational theories and has been well-studied by researchers of educational theories to discuss ways to motivate students attending a laboratory training course. Among the several factors that comprise the motivation theory, we focus on "enactive mastery performance" and "verbal persuasion" in our attempt to design digital aids that incorporate these factors. Providing digital aids and learning steps for use in preparation and review is expected to help students better understand how to manipulate devices and tools and better perceive the transformation of materials during an experiment.

2. Learning Topics and Learning Steps

This chapter analyzes the learning topics and steps used in existing laboratory training courses. We classify course topics into knowledge and practical skills, and examine whether adequate guidance is provided to students to allow them to acquire skills, with the aim to identifying the learning styles peculiar to laboratory training courses.

2.1 Learning topics

By referring to several laboratory tutorials published in the field of science and engineering and other similar academic disciplines in Japan, we classified course topics into knowledge and practical skills. The results are summarized in Table 1.

Because we were unable to find any existing literature that reports on the kind of classification provided in Table 1, we referred to several laboratory tutorials to classify course topics into the aforementioned two categories.

Table 1: Course topics classified into knowledge and practical skills

Knowledge	(K1) Objectives of the experiment, (K2) Names of devices and tools, (K3) Functions of devices and tools, (K4) Mechanisms of material transformation (through chemical reactions, machining, etc.), (K5) Procedures, (K6) Observation methods, (K7) How to evaluate results (how to create and evaluate tables and charts, how to assess finished works), (K8) Background experiment information necessary for making observations
Practical skills	(S1) Manipulation skills (ability to use devices and tools safely and in an optimum fashion) (S2) Coordination skills (spatial ability, preparation skills) (S3) Insight (ability to speculate the state of a target and causes based on information such as sound, vibration, light, and temperature)

For example, individuals having the "manipulation skills" in the practical skills category in Table 1 should be able to move their body to reach the necessary tools and materials, and based on the knowledge of how such tools and materials function, use their hands and body to manipulate them in the most efficient manner, while observing all the safety precautions required for experiments. Individuals having the "coordination skills" should be able to recognize the space around them so they know where they can find what they need and make all the necessary preparations, including placing the tools and materials in proper positions before and after manipulating them, and planning how to position their body. Individuals with "insight" can make inferences and predictions based on the perception of the state of the objects and environment around them, and, based on those inferences and predictions, evaluate the present situation and prepare for the future. All these skills require not only careful coordination of multiple perceptions and multiple body parts but also the ability to plan, prepare, act, and guess. The practical skills summarized in Table 1 involve physical activity (i.e., "manipulation") and the perception of phenomena, coupled with knowledge and experience (i.e., coordination skills). Thus, these skills can probably be evaluated by using the psychomotor skills domain of the taxonomy.

The acquisition of these skills requires good coordination between the body and senses. This coordination can be explained as a kind of sensorimotor integration, a term that is used in the fields of welfare and medical science and sports science. Skills learning that enables such integration must consider covering several topics including evaluation of knowledge gained as a result of manipulation, memorization of skills, and transfer of skills, all of which must be accompanied by guidance on appropriate repeated practice (Yamauchi & Haruki, 1985).

Laboratory training courses are characterized by their goal of accomplishing sensorimotor integration, which sets them apart from lecture-style courses that do not involve physical activity. However, most laboratory tutorials focus on the acquisition of knowledge, providing little guidance on how to encourage students to take time to engage in repeated practice to acquire skills. This can be attributed to the limited time allotted to each session and the capacity of instructors (availability of only one instructor to tutor a number of students).

2.2 Learning steps

By referring to several laboratory tutorials and typical time schedules adopted for laboratory training, we summarized the standard learning steps as follows:

L1: Summon students to a laboratory by the specified time.

L2: The instructor explains the objective of an experiment by referring to an experiment guidebook.

L3: The instructor explains the name of each device, their functions, how to manipulate them, and (safety) precautions to be observed during the experiment.

L4: The instructor demonstrates how to conduct the experiment. (This step is sometimes omitted.)

L5: Students take measurements by manipulating devices and take notes of the findings.

L6: The instructor observes how students are doing and provide instructions as necessary. (This step is sometimes omitted.)

L7: Students prepare reports by referring to their notes, and submit them to the instructor for evaluation.

These steps have the following problems:

L1: Students may not have the skills necessary to conduct the experiment. Most curricula are planned based on the assumption that students will acquire most of the necessary skills by following the experiment procedure and undergoing practical training.

L3 and L4: Even when the instructor tries to give a thorough explanation within a limited time frame, students may end up engaging in practical part of the session feeling unsure of themselves due to the lack of basic knowledge and skills. This kind of experience can give students a negative mindset (frustration and doubts associated with not being able to do things right), which can hamper the effort to maintain and improve the quality of education.

L6: Irreversible material transformation occurs in parallel with the physical activity of students during an experiment, making it extremely challenging for the instructor to simultaneously observe all the students' behavior and the state of their experiments. Furthermore, only a limited time slot is allotted for each laboratory training session, which is often not enough to deliver all the necessary instructions.

These problems suggest that learning steps designed for conventional laboratory training sessions may not be adequate enough to provide efficient and effective learning experience to students with limited skills.

3. Learning Topics and the Taxonomy

3.1 Classifying learning topics

In Chapter 2, we classified learning topics into knowledge and practical skills. In this chapter, we sort learning topics into different taxonomy levels in an attempt to examine the characteristics of each learning topic. The taxonomy can be represented in two dimensions, i.e., the cognitive process dimension (6 levels) and the knowledge dimension (4 levels) (Anderson et al., 2001). The sorting result is summarized in Table 2.

Table 2: Sorting laboratory training learning topics into different taxonomy levels

Knowledge dimension	Cognitive process dimension					
	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
A. Factual knowledge	K2	K3, K4	K3	K8		
B. Conceptual knowledge		K1, K3-8, S4			K7, K8	
C. Procedural knowledge		K5-7, S1-3	S1	S3		
D. Metacognitive knowledge		K1, K7-8				

This sorting was determined by referring to the laboratory tutorials for the first- and second-year undergraduate students and based on the analysis of the content of each course topic. The *6. Create* column is empty because undergraduate students are not expected to demonstrate this ability during course sessions.

We are aware that learning topics shown in Table 2 can be sorted differently. For example, factual knowledge and conceptual knowledge may not be the only dimensions relevant to the mechanism of material transformation (topic K4). Materials could transform in various different ways depending on the procedure used by a student, and the student might choose to use a certain procedure based on his factual and conceptual knowledge, in which case, K4 could be used as a topic to help students acquire procedural knowledge (knowledge dimension C). It is important to remember that a taxonomy can have several different variations depending on the field and method of education.

We placed practical skills S1-3 in the procedural knowledge dimension (dimension C) because these skills require the basic knowledge of how to manipulate devices and tools, how to select an appropriate method of manipulation, and how to pay careful attention to and observe the situation at hand and the changing state of materials. Now, let us explain why S1 is in both dimensions 2 and 3 by taking scissors as an example.

- Understand: Understand how to slide fingers through the handles of the scissors, how to move the blades, and how to position the blades against the material.
- Apply: Apply knowledge to make tiny cuts in materials or to use different cutting techniques for different materials.

As shown in this example, students learning how to manipulate devices and tools are often asked to use (or apply) their understanding of how devices and tools work to manipulate them in a manner different from what they have learned (e.g., try different cutting techniques with scissors).

3.2 Discussions

The taxonomy shows that many of the basic learning topics are concentrated in the *Understand* dimension (dimension 2). Understanding requires certain knowledge regarding the physical and social background of the topic concerned, and, in the case of laboratory training courses, somesthetic senses associated with physical activity that resembles the one used in laboratory settings (Murakami Y. , 2007). The same applies to the conceptual knowledge and procedural knowledge dimensions (dimensions B and C).

Taken together with the problems discussed in Chapter 2, this finding suggests that students lacking sufficient knowledge and practical skills do not reach the state of understanding (dimension 2 in the taxonomy) until they actually attend training sessions. This also means that they are implicitly expected to reach that state during the training sessions. Failing to do so within the limited time slot allotted to each training session can cause students to lose the motivation for learning.

Acquisition of practical skills can have a huge impact on the students' motivation to learn in laboratory training sessions and their willingness to continue learning. The next chapter discusses how to motivate students and sustain their willingness to continue learning.

4. Motivation and Self-Efficacy

4.1 Motivation

So far, we have explained how the lack of explicit instructions related to the acquisition of skills during laboratory training sessions can exert a negative impact on the students' motivation for learning. This problem can lead to a loss of motivation for learning and willingness to continue learning, which is one of the major issues addressed in the theory of learning.

We believe that it is essential to provide some form of motivation to students in order to encourage them to continue learning. As is well-known, there are two types of motivation: extrinsic motivation and intrinsic motivation. Although extrinsic motivation can be effective in encouraging students to learn during an early stage of learning, many experts agree on the importance of eventually enhancing intrinsic motivation to allow students to develop their independent learning attitudes (Kage, 2018). In view of this, this section examines textbooks used in laboratory training courses to determine whether these textbooks provide extrinsic motivation or intrinsic motivation more.

In textbooks, we often encounter phrases such as "the objectives of this experiment are..." or "this result is important because...". Phrases like these can be regarded as extrinsic motivation. On the other hand, we found no textbooks that describe how to nurture intrinsic motivation in students. This is probably due to an assumption that once students are engaged in an experiment, they will naturally be interested in it and spontaneously conduct the experiment. If this assumption is true, intrinsic motivation will emerge and students will maintain their willingness to continue learning. However, many young people today are said to have limited environments and opportunities for moving their body to exercise their skills (Guthold et al., 2020). If that is the case, failure to move their body and set up an experiment in a proper manner will give rise to negative feelings, causing some students to lose their interest in the experiment or feel reluctant to engage in it, preventing them from properly building intrinsic motivation.

We would like to propose a solution for this problem. To promote greater efficiency in learning, our intention is to provide a measure that encourages self-directed learning without the aid of the instructor, with focus on the self-efficacy aspect of motivation. Our assumption is that, if we could enhance self-efficacy in students, then it will in turn contribute to building intrinsic motivation in them. In view of this, we will discuss how a digital aid can be utilized to build self-efficacy in students.

4.2 Self-efficacy

Self-efficacy is the perception of one's competence to successfully select and take a course of proper action to achieve a specific goal. In short, self-efficacy can be defined as "confidence". It is important to remember, however, that self-efficacy does not refer to baseless confidence. Rather, it is self-confidence based on solid evidence, which gives individuals the ability to think positively about themselves. Self-efficacy is known to consist of the following factors (Bandura et al., 1997; Kelley et al., 2020):

i. Enactive mastery performance: To accumulate one's own experience of success.

ii. Modeling: Self-efficacy can be enhanced by witnessing or learning about successes experienced by other people.

iii. Verbal persuasion (social persuasion): To be persuaded by someone else about one's competence to accomplish certain tasks.

iv. Psychological states: To maintain healthy mind and body.

As the first step of our study, we focused our attention on (i) and (iii) and made the following observations.

4.2.1 Enactive mastery performance

During an early stage of learning, we believe that there should be a way to allow students to acquire the following knowledge prior to attending a session.

- Prior knowledge of spatial information of the laboratory: Being able to spatially grasp the whereabouts of equipment, devices, tools, and materials beforehand gives students the confidence to prepare for an experiment in the actual laboratory. This could help dispel feelings of insecurity among novice learners.
- Understanding of the name of each device/tool, how they function, and how to use them: Prior access to information about course topics allows students to better understand the instructions provided by the instructor.

Acquiring these knowledge and understanding prior to the upcoming session gives them "virtual past performance", which makes them feel that they already know the whereabouts of all the things they need for an experiment and can therefore smoothly prepare for an experiment in the actual laboratory.

4.2.2 Verbal persuasion

During an early stage of learning, there are still so much to be learned that students often fear or worry about failure or how their performance will be evaluated. Praise is one of the coaching skills that is believed to be essential for sustaining continued learning (Finn, 2020). Considering the nature of laboratory training sessions, however, praising the process that leads to a failure results in negative educational consequences. An effective alternative to praise would be to welcome the student's attitude of asking questions. In Chapter 5, we will discuss how to build self-efficacy in students.

5. Proposal of Digital Transformation Design Principles

5.1 Design principles

This section describes the design principles concerned with past performance and verbal persuasion. Past performance design applies to preparations for an upcoming training session, whereas verbal persuasion design applies mainly to review of the previous session.

5.1.1 Enactive mastery performance design

Prior knowledge of spatial information of the laboratory and understanding of the name of each device/tool, how they function, and how to use them: The design for this learning experience involves creating a digital footage that starts from the entrance of the laboratory to show students where they can find each device/tool they need inside the laboratory, and explains how each device/tool works. This digital aid can help reduce a psychological barrier to facing unknown information and give students the knowledge that can be gained through their spatial ability. Furthermore, the digital footage can be played repeatedly on an on-demand-basis for imagery rehearsal, allowing students to not only understand (dimension 2 in Table 2) the delivered information but also gain procedural knowledge (dimension C in Table 2).

Students preparing for a training session could incorporate this digital aid for iterative learning, which would allow them to gain "virtual past performance". The digital aid can also help students acquire the skills described in Chapter 2. Coordination skills, for example, are necessary for efficient execution of tasks and manipulation. Several previous studies claim that the acquisition of these skills is a prerequisite for becoming a competitive worker in the field of manufacture (Bryant, 2009; Doi, 1998; Ohashi, 2005). These studies suggest that the following ability and skills are needed to acquire coordination skills.

- Spatial ability: This refers to a 3D spatial ability, which is essential for finding where all the devices, tools, and materials are. Students with this ability can prepare themselves for the next bodily action to be taken, allowing them to naturally make the next move without having to think too hard about it.
- Preparation skills: In the field of sports science, preparation refers to a physical and psychological stance taken prior to making a move (Fukashiro S. , 2010; Murakami Y. , 2007). In addition to this, individuals having preparation skills should be able to predict their next move (e.g., whether they should be moving to a different area in the room to perform a task or rearrange their posture) in a way that suits the properties of the devices/tools and materials they are manipulating. In the field of education, the term "learning set" encompasses such preparation skills.

Although these skills are essential for smooth conduct of experiments, few laboratory tutorials address the acquisition of these skills. Given the importance of "virtual past performance" in acquiring coordination skills, we believe that an entry-level digital aid for novice learners that provides guidance on coordination skills will help students acquire the skills necessary to prepare for experiments.

5.1.2 Verbal persuasion design

We propose the use of a chatbot that provides a message saying that it welcomes the student's attitude of asking questions. Assuring students that their questions are welcome has a good psychological impact on them, making them feel at ease to ask a question and encouraging them to ask even more questions. Thus, offering this digital aid as a tool to assist students in reviewing the previous session has the potential to trigger motivation for learning and ensure continued learning. In view of this, we used the proposed DX-based course design approach to devise the learning steps summarized in Figure 1.

Figure 1 can be summarized as follows. Students prepare for the upcoming session by building awareness of the space inside the laboratory, learning how to use devices and tools, and using on-demand digital footage to practice imagery rehearsal of their use. Those students who are well-prepared are allowed to start on on-site practical training. Learning through this process is expected to be more efficient than learning attained by following the conventional experiment procedures. After the training session, students can rely on a chatbot when any questions come up while reviewing the previous session. Because the chatbot always welcomes questions, students feel at ease to ask more questions, which contributes to sustaining their willingness to continue learning.

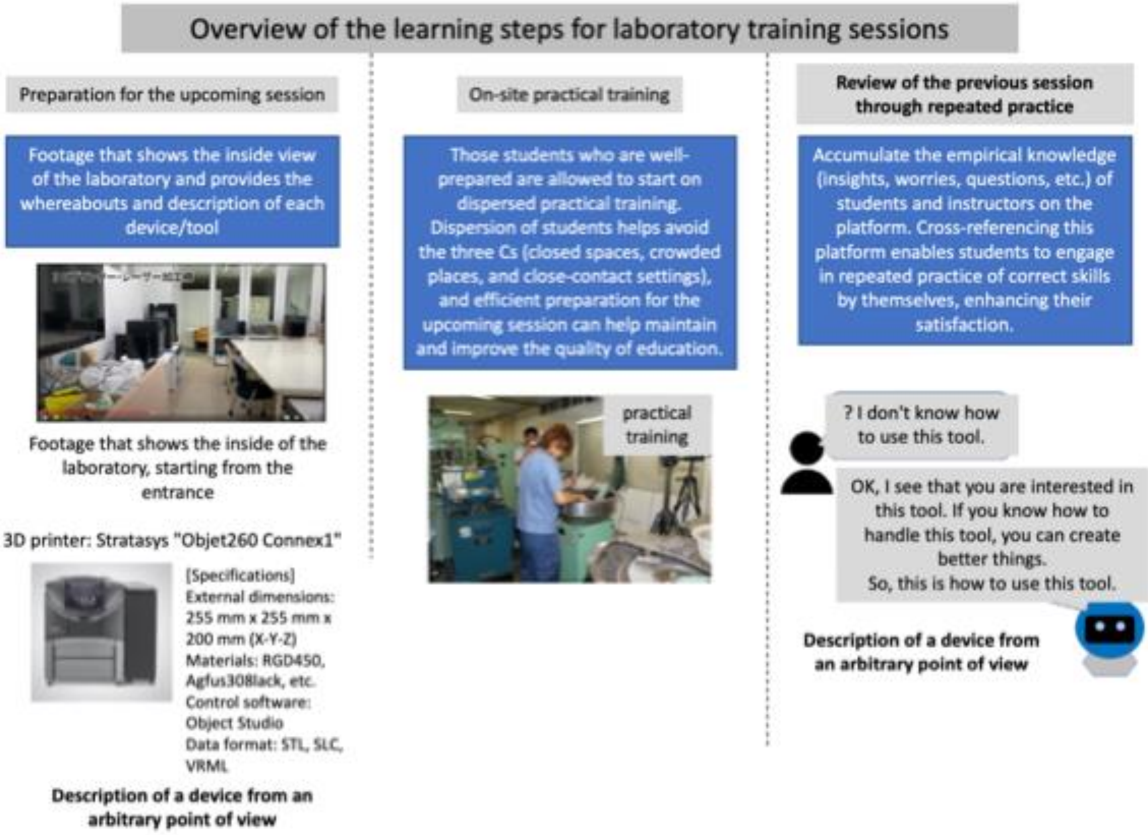

Figure 1: Overview of the learning steps

5.2 Example of past performance design

This section presents an example of a course designed to learn about equipment (an equipment course). During an equipment course, an instructor gives on-site face-to-face instructions to students about the basics of how to use a prototyping/manufacturing facility and the precautions to be observed in such a facility. Conventional equipment courses have the following issues:

i. Because most students have never been inside a prototyping/manufacturing facility before, they have difficulty paying attention to their surroundings, and end up concentrating their attention only on the instructor, trying hard to catch every word the instructor is saying.

ii. This makes them less likely to perceive the spatial arrangement of devices, tools, and materials around them. Because of this, when they visit the facility again for the next session, they often have difficulty setting up the devices, tools, and materials.

iii. Furthermore, because on-site oral instructions are given only once, when students miss the chance to ask questions, it is hard for them to find solutions to these questions by themselves (this effort is referred to as "review" (of the previous session)). Introverted students are unable to ask the instructor for help about some questions concerning the previous sessions. As a result, they end up attending the subsequent sessions without their questions clarified, which can have a negative impact on their learning.

In an attempt to address issues i and ii, we created a digital aid that incorporates the following design requirements:

1. The instructor creates a digital footage in which the instructor provides a tour of the facility starting from its entrance to explain the 3D spatial arrangement of the inside of the facility and all the equipment in it from the students' point of view.
2. After the tour, the instructor approaches each device, tool, and material to explain them.

The explanations given in accordance with Requirement 1 must have the first person shooter effect (FPS). Specifically, as the instructor gives a tour of the facility, the digital footage should capture only the hands of the instructor and the audio guidance. The FPS effect is important because it can help viewers acquire psychological motion that can serve as empirical knowledge gained through hands-on experience, in addition to providing virtual experience that consists of spatial recognition and perception and motion of the body (Seya Y., 2016; Wu & Spence, 2013). Explanations given in accordance with Requirement 2 are designed to provide "virtual past performance" to viewers. Viewers can play this on-demand digital footage repeatedly until they understand the audio guidance on the external appearance of equipment and how to operate it.

A chatbot that answers questions from students is provided as a solution to issue iii, which is designed to assure students asking good questions that they are indeed asking good questions and praise them for asking questions. Both Figure 2 and Figure 3 show part of a digital footage providing a tour of the facility, which provide solutions to issues i and ii.

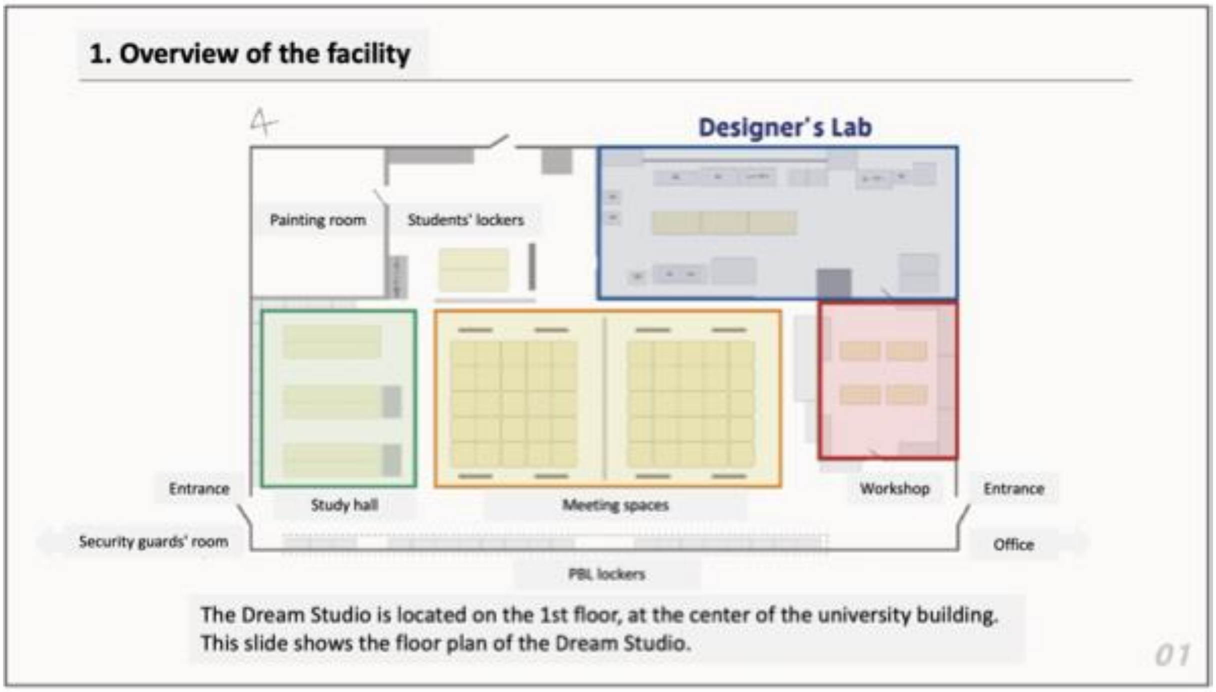

Figure 2: Part of the digital footage providing a tour of the facility (floor plan of the facility)

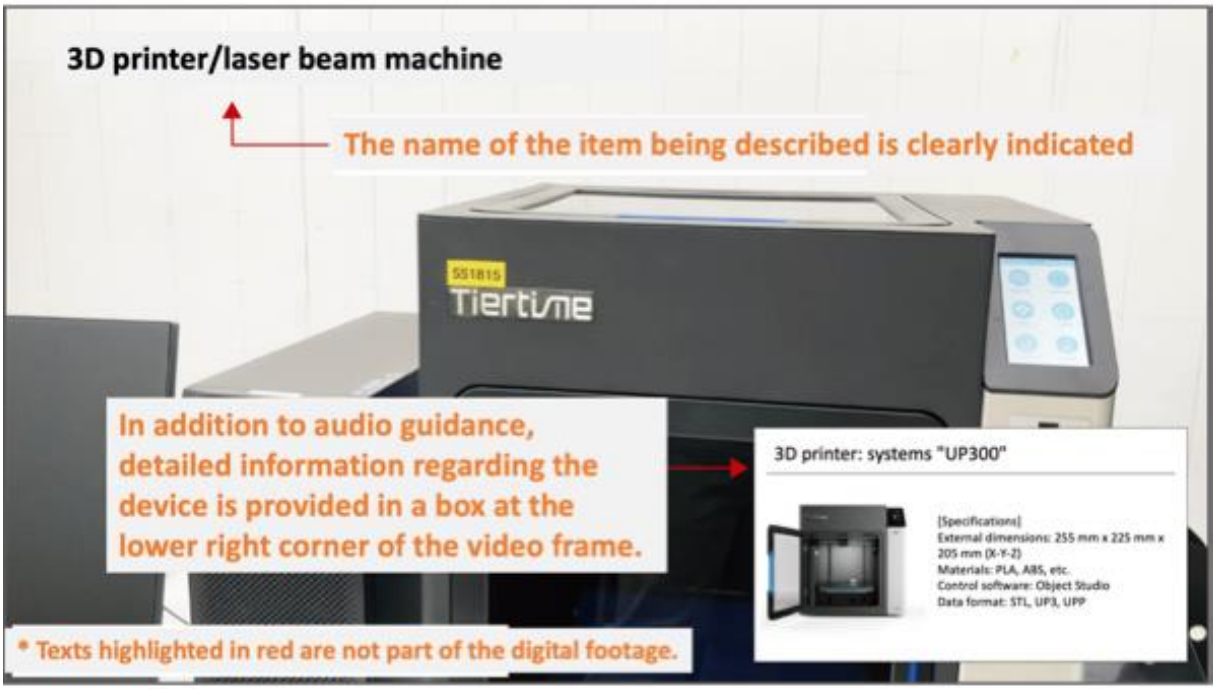

Figure 3: Part of the digital footage providing a tour of the facility (explanation of devices)

This digital footage is based on the following design specifications:

- Provide a floor plan of the entire facility to facilitate spatial recognition of the facility by viewers and to explain each area. Afterwards, use video footage of the facility to provide more detailed information, including how to use the facility (Figure 2).
- At the top left corner of the video frame, clearly indicate the name of the item being described. Provide captions synchronized with audio guidance at the lower middle portion of the frame.
- When an audio guidance on a specific device is playing, the details of the device must be displayed in a box located at the lower right corner of the video frame (Figure 3).

The floor plan of the entire facility is provided to allow students to have a detailed understanding of the layout of the facility. A video footage providing a tour of the facility is played afterwards. This footage helps students gain spatial recognition of a facility they have never visited before, allowing them to acquire certain "preparation skills" that they will need when they actually use the facility.

This video footage also displays a box showing a detailed description of the device to reinforce the understanding of the information necessary to actually use the device. The locations of the texts displayed in the video footage are arranged to allow the viewers' gaze to drift from upper left to lower right corner of the video frame, which enables viewers to capture information with greater ease. The color of the box displayed at the corner of the video frame contrasts sharply with the image in the background to allow greater viewability for students.

5.3 Example of a chatbot designed to provide verbal persuasion

We conducted a questionnaire survey of a total of 22 students (5 females and 17 males) to obtain feedback on the digital contents described in the previous section. From the questionnaires returned, we extracted all items that were difficult to understand for the respondents, and further narrowed them down to those that can be clarified with text information, and incorporated that text information into a chatbot. To boost self-efficacy, each reply from the chatbot is preceded with the following sentence that welcomes the student's question.

- Question: "Can you tell me how to use the devices, the type of material to be used, and the size of an object I can create?"
- Reply: "I am happy to oblige because these things are important for novice learners. (Response to the question)". This reply acknowledges that the student has asked an important question.
- Question: "Is it possible to edit scanned data?"
- Reply: "Editing is necessary to correct problems like scan errors." By indicating that editing is a necessary task, the chatbot assures the student that he/she has asked an important question.

Figure 4 shows a portion of an interaction with the chatbot in which the chatbot welcomes questions from students.

Figure 4: Example of replies provided by the chatbot

Welcoming questions from students and giving them the information they need is equivalent to giving them verbal persuasion, even when it is just an interaction taking place in a virtual space. In other words, having a digital aid that welcomes their questions and feeling at ease to ask any questions give students a sense of security, which can enhance their self-efficacy, motivating them to take initiative for their own learning.

6. Conclusion

In an attempt to effectively introduce DX into a laboratory training course, this paper divided course topics into knowledge and practical skills, examined them from the perspectives of taxonomy, motivation, and self-efficacy, identified some issues inherent in the current training sessions, and made some suggestions for improvement. With these suggestions for improvement in mind, we presented an example of how to create a digital aid that provides (virtual) past performance and verbal persuasion to students. An interview/questionnaire survey conducted on several students revealed our digital aid to be useful for self-directed learning, although the results were not statistically significant. We will continue to pursue this study to validate the effectiveness of our digital aid by increasing the sample size for an interview/questionnaire survey.

In this paper, we only addressed the taxonomy of course topics and failed to consider the classification of objectives in the skills domain (Harrow, 1972; Simpson, 1970). This shortcoming will be addressed in our future investigation.

This digital aid can be used for imagery rehearsal to prepare for the upcoming session, and those students reaching a certain level of preparedness quickly can proceed to the on-site practical training sooner than those who have not reached that level, which can help disperse the number of participants present in the room at a particular point in time, as compared to the conventional scheme where all students simultaneously proceeded to on-site practical training. Dispersion of students would be effective for controlling the spread of viruses, which is in fact one of the objectives of offering this digital aid.

This paper represents one of the achievements accomplished as part of the project titled "Building a Co-Creative Skills Learning Platform for the Sophistication of Skills Education" that was adopted as Project (2) of the 2021 Plan for Universities/Colleges Aiming for a Smart-Campus Through Digital Transformation (Ministry of Education, Culture, Sports, Science and Technology). It was approved by the Research Safety and Ethics Committee of the Advanced Institute of Industrial Technology (No. 21003).

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