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TRANSFORMATIVE LEARNING MODEL WITH DIGITAL FABRICATION LABORATORY TO ENHANCE INNOVATION COMPETENCY AND CREATIVE PRODUCT

SUNTI SOPAPRADIT[1], PRACHYANUN NILSOOK[2] & PANITA WANNAPIROON[3]

[1] Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, Thailand

E-mail: [1]Suntispp@gmail.com

ABSTRACT

This research's objectives were 1. To develop system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product. 2. To study the results of the demonstration system. The study included 2 process: 1) the development system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product, and 2) the result of the demonstration system. The use of transformative learning with digital fabrication laboratory was demonstrated to students in Southeast Bangkok College who registered for the 'Industry Innovation Laboratory' subject in their first semester of B.E. 2565. The findings revealed that the scores with regard to 1) the curriculum, 2) the context quality, 3) the quality of the lecturing media, and 4) the quality of the learning system were rated as being at the highest level. Moreover, after studying the subject, the experimental group had greater innovation competency scores than they exhibited prior to the learning process. In addition, the experimental group had higher scores with regard to innovation competency and creative product after studying than the control group and the criteria. A system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product is a new teaching model that can develop students' skills in the 21st century. Therefore, it should be applied to other subjects in this field by only subjects that are practiced so that students can develop their own skills.

Keywords: *Transformative Learning, Digital Fabrication Laboratory, Innovation Competency, Creative Product*

1. INTRODUCTION

In the digital era, information and communication technology (ICT) is a tool that assists in many aspects of everyday life such as working, communicating, and teaching. Additionally, ICT also supports the country's development in various industries [1] such as business, medicine and other industries included in the 'industrialization 4.0' era. This has resulted in a shift from labour utilization to innovation and mechanical adaptation. Thus, a broad range of goods are now efficiently produced by using customized materials in line with each consumer's particular requirements [2]. As previously mentioned with regard to change, the education industry needs to adapt by designing learning models that can handle change in order to keep pace with technological improvements in such a way as to facilitate students' entry into the labor market.

Transformative learning is considered as a model that emphasizes the learners' ability to reflect on their own experiences based on their personal thoughts, feelings, and beliefs. This affects the learner's daily life, interaction with other people, and the environment around them. The transformative learning process focuses on allowing students to participate in experiments in order to obtain direct experience in a variety of learning areas, especially in terms of exploring and challenging their own values and beliefs. This leads to better consideration and observation that supports the students when it comes to seeing the root causes of problems [3]. The students can also share what they obtain with each other to find a solution [4]. Nowadays, modern technology associated with teaching and learning is being used to develop a new paradigm for learning in order to make students more efficient and proficient in a variety of areas [5] such as with regard to skills related to research, analysis, synthesis, reflection, creativity and imagination [6]. This helped students to develop a range of innovation [7].

As mentioned in the previous paragraph, transformative learning is a learning paradigm that encourages students to innovate. In order to do so there must be a study location where students may experiment and practice. Digital fabrication

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laboratories have been widely utilized to develop innovation [8], [9], [10]. This consisted of learning systems and modern technology equipment in terms of both hardware and software [9], [11]. The digital fabrication laboratory is a teaching and creative design [12] that encourages students to engage in innovation. Such a laboratory may be outfitted with a variety of high-tech equipment and devices such as laser cutting machines for 2D & 3D model-making, CNC milling machines for making circuit boards and specific parts, 3D printing machines, and scanners. These devices use computer software to operate them in order to manufacture items [13] as a change from abstract thought to be in favor of practical material output [14]. Additionally,a digital fabrication laboratory is also a place where students and technologists may share and generate knowledge in a variety of sectors [13], [15].

From the policy of the industrialization 4.0 era, which the old teaching model cannot respond to, it is necessary to develop a new teaching model to respond to the national policy. Therefore, the researcher decided to develop transformative learning with digital fabrication laboratory to enhance innovation competency and creative product, as a means of supporting digital learning and technological practice [16] in order for students to have the skills to be able to enter the labor market in the future.

2. RESEARCH OBJECTIVE

2.1 To develop system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product.
2.2 To study the results of the demonstration system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product.

2.2.1 To compare innovation competency score of the experimental group before and after studying.

2.2.2 To compare innovation competency and creative product scores of the experimental group and the control group after studying.

2.2.3 To compare innovation competency score of the experimental group after studying and the criteria (60 percent).

2.2.4 To compare creative product scores of the experimental group after studying and the criteria (60 percent).

3. RESEARCH METHODOLOGY

3.1 The development of a system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product. The details are as follows:

1. The researcher analyzed and synthesized principles, concepts, and theories related to transformative learning (TL) by considering the publications of Mezirow [17], Mayo [18], Sharpe [19], Beer [20], Jacobs [21], Yıldırım and Yelken [22] and Johnson and Olanoff [23] consist 10 processes: 1) Disorienting Dilemma 2) Self-Examination 3) A Critical Assessment of Assumptions 4) A Recognizing of a connection between one's discontent and the process of transformation 5) Exploration of options for new roles, relationships, and actions 6) Planning a course of action 7) Acquiring knowledge and skills for implementing one's plans 8) Provisional Trying of New Roles 9) Building competence and self-confidence in new roles and relationships and 10) A Reintegrating into one's life on the basis of condition dictated by one is new perspective. The researcher found some steps of transformative learning are continuous processes. Therefore, he researcher regrouped the transformative learning steps into 5 steps: TL1) Learning Change: consists of 2 sub-steps: TL1.1: Self-Examination: and TL1.2: Acceptance of Change TL2) Find a new conceptual framework TL3) New Planning TL4) Testing TL5) Integrating new Competency and Perspectives consists of 2 sub-steps: TL5.1: New Competency and TL5.2: New Perspectives as shown in Figure 1.

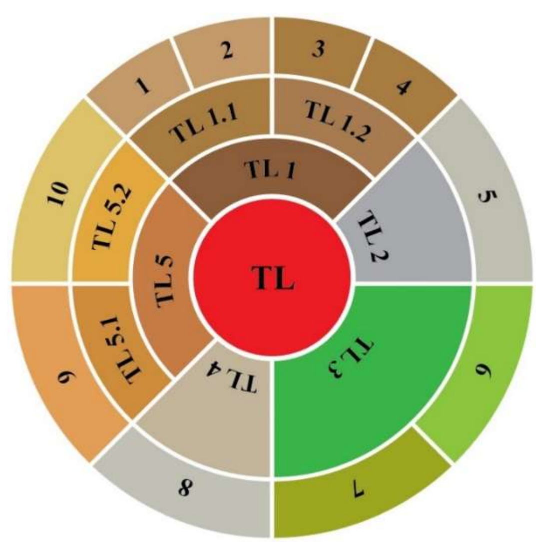

Figure 1: Process of transformative learning

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Additionally, The researchers analyzed and synthesized principles, concepts, and theories related to the use of Digital Fabrication Laboratories (DF) by considering the publications of Lewis and Clark [24], Hamid et al. [25], Lorenzo et al. [26], Lee et al. [8], Putro and Wirasmoyo [27], Soomro and Georgiev [9], Hsieh and Chang [10] and Formlabs [28], together with the components of tools used in the Digital Fabrication Laboratory by considering the publications of Yildirim et al. [22], Gadjanski et al [29], Poustinchi [6], Lorenzo et al. [26], Soulaf et al. [30], and Cornetta et al. [11] consist 4 process : 1) Design : DF1 2) Prepare : DF2 consists of 4 tools: 4.1) hardware, 4.2) software, 4.3) material for making the product, and 4.4) online storage and simulator tools. 3) Fabricate : DF3) and 4) Assembly and Installation : DF4) as shown in Figure 2.

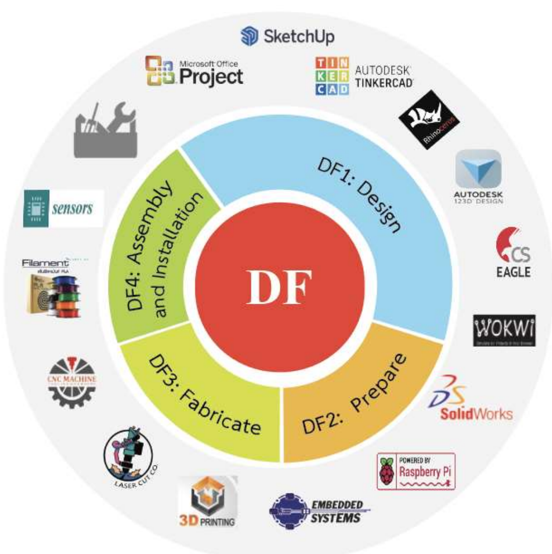

Figure 2. Digital Fabrication Laboratories and tools

As mentioned previously, the researcher led the process of transformative learning and digital fabrication laboratory to develop a system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product. The researcher designed and developed the system according to the concepts of the software development life cycle entitled the Adapted Waterfall model, because this design method is extremely adaptable, with the ability to modify, change, and add functionalities and task modules as needed [31]. It is also consistent with the four-step operational procedure:

Step 1 : Learning Change (TL1) and Finding a New Conceptual Framework (TL2) are components that relate to one another, and are in line with Design (DF1). When the students found that their previous experience of technology was not related to the new technology, they had to find the necessary information and exchange it with other people. This process created new experience related to the new technology. This in turn allowed them to build a new conceptual framework to solve problems related to the new technology. This allowed them to engage in creative product planning leading to a practical outcome.

Step 2 : New Planning (TL3) was consistent to Prepare (DF2). The students used this to arrive at a solution to solve the problem associated with the new technology to create creative product. The students then prepared 4 types of tools for this purpose 1) hardware, 2) software, 3) material for making the product, and 4) online storage and simulator tools. The students also practiced and learned how to use these tools in order to hone their skills.

Step 3 : Testing (TL4) was in line with Fabrication (DF3). This was done according to the plan. The creative product was designed with the use of programs such as Solidworks, Autodesk 123 Design, Rhino and CS Eagle. The product would then be produced using 3D printing, Laser Cutting and CNC machines.

Step 4 : Integrating new Competencies and Perspectives (TL5) was in line with. Assembly and Installation (DF4). After the students had completed testing, each component was brought to be assembled in order to create product. Electronic devices such as sensors and embedded system were installed to control the designed functions. As a consequence, the students increased in competency and enjoyed better self-esteem. Moreover, they were able to adapt the knowledge that they developed to create other creative products as shown in Figure 3.

2. The researcher created 4 types of evaluation form to support the teaching and learning associated with the system of transformative learning with digital fabrication laboratory enhance innovation competency and creative product.

These forms were evaluated by 7 experts who had 1) doctoral degree, and 2) five years or more experience in Information and communication Technology. Purposive sampling was used to select the sample for this study to check the quality of details and language as well as the completion of the questionnaire with Index of Item Objective Congruence (IOC). A five-point Likert scale was used in this study, from 5 indicating the highest rating to 1 indicating the lowest.

The forms were are follows: 1) Quality of the curriculum 2) Context quality 3) Teaching-learning media quality and 4) Teaching-learning media quality. The data was analysed in terms of mean ($\bar{X}$) and standard deviation (S.D.). The actual scale used to rank the suitability of the overall assessment of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product was more granular with the following five levels: 4.50 - 5.00 indicating the highest suitability, 3.50 - 4.49 - high, 2.50 - 3.49 - medium, 1.50 - 2.49 - low, 1.00 - 1.49 - indicating the lowest suitability. The results showed that the overall quality of 1) the curriculum, 2) the context quality, 3) the quality of the teaching-learning media and, 4) the quality of the learning system were ranked as being of the highest as shown in Table 1.

Based on the previous paragraph, the researchers were able to conclude that the system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product could be utilized as a guideline for creating a learning system that could develop innovation competency in such a way as to encourage creative output.

3. In addition, the researcher created 2 evaluation forms: 1. Innovation Competency and 2. Creative Product. The innovation competency form was adapted from the evaluation test of Keinanen et al. [32] and has 5 competencies: 1) Creative problem solving 2) Systems thinking 3) Goal orientation 4) Teamwork and 5) Networking. The innovation competency is a self-assessment. This evaluation of innovation competency is a three-point self-assessment and has 22 assessments.

The adaption of four tiers of rubrics resulted in the creation of the creative product according to the concepts of Besemer and Treffinger [33] and Wongwanich [34] which have ten questions and a score of 0-3. This study was evaluated by 7 experts who had 1) doctoral degree, and 2) five years or more experience in Information and communication Technology. Purposive sampling was integrated in this study. To check the quality of details and language as well as the completion of questionnaire, Index of Item Objective Congruence (IOC) was utilized.

The consistency between the evaluation form and the intended purpose was measured by the experts' opinions on each question, with +1 indicating consistency, 0 - not sure and -1 indicating lack of consistency All the questions were rated as +1, hence they were consistent with the intended purpose. The criterion for determining the calculated IOC index value must be more than or equal to.05 [35]. The Index of Item-Objective Congruence (IOC) score

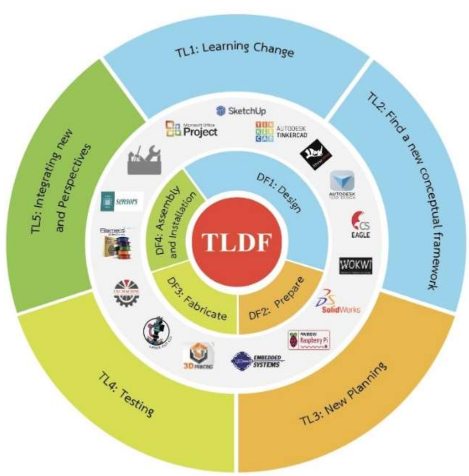

Figure 3. The Conceptual Framework

Table 1. The Result Of The Overall Assessment Of Transformative Learning With Digital Fabrication Laboratory To Enhance Innovation Competency And Creative Product.

Types of evaluation	$\bar{X}$	S.D.	Appropriateness Level
Quality of the curriculum	4.52	0.47	highest
Context quality	4.54	0.49	highest
Teaching-learning media quality	4.51	0.48	highest
Teaching-learning media quality	4.52	0.47	highest

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was 1.00, with an intercorrelation value of 0.84. Furthermore, the instructor took the innovation competency assessment and tested it on 30 students to find the reliability value by using Cronbach's Alpha Coefficient. The reliability value was equal to 0.93, which could be described that this innovation competency assessment was practical.

3.2 The result study of the demonstration the system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product.

1. Research Hypothesis

In this study, the researcher had set 4 hypotheses as follows:

1.1 After studying, the experimental group had higher innovation competency score than before studying.

1.2 After studying, the experimental group had higher innovation competency and creative product scores more than the control group.

1.3 After studying, the experimental group had innovation competency scores more than the criteria (60 percent).

1.4 After studying, the experimental group had creative product scores more than the criteria (60 percent).

2. Population and Samples

2.1 Population

The population was the cohort of Bachelor's degree students who enrolled in the science and technology major offered by the Southeast Bangkok College in the first semester of B.E. 2565.

2.2 Sample

The sample group consisted of 2 classes of students who registered for the industry innovation laboratory subject in the first semester of B.E. 2565. Simple random sampling was implemented. The classroom was the sampling unit, which was used in order to classify the students as either an experimental group or as a control group. The experimental group consisted of those students who studied using the system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product, whereas the control group consisted of students who studied in a traditional teaching-learning context. The results revealed that the innovation competency of the experimental group and the control group before studying the subject was not different at a significance level of 0.05 as shown in Table 2.

3. Variables in this study

3.1 Dependent variable were innovation competency and creative product.

3.2 Independent variable was the system of transformative learning with digital fabrication laboratory.

4. RESEARCH RESULTS

The details of the research hypotheses are as follows:

Hypothesis no. 1: After studying, the experimental group had higher Innovation Competency score than before studying.

In terms of Hypothesis No. 1, the mean innovation competency score of the experimental group before studying was 46.48 with a standard deviation (S.D.) of 6.55. However, the mean innovation competency score of the experimental group after studying was 60.40 with a standard deviation (S.D.) of 4.98. Consequently, after studying the experimental group had a higher innovation competency score than before studying at significance level of 0.05. Furthermore, after studying the subject, the experimental group had higher innovation competency score than before at 13.92. This complies with Hypothesis No. 1 as shown in Table 3.

Hypothesis no. 2 : After studying, the experimental group had higher innovation competency and creative product score than the control group.

In terms of Hypothesis No.2, the researcher analyzed this data set by using one-way MANOVA since this data set was consistent with one-way MANOVA Assumption Statistic Test (Levene's Test, and Test Box's M Test) at a non-significance level of 0.05, and at a significance level of 0.05 for Bartlett's Test of Sphericity as shown in Table 4.

The analysis result with regard to the one-way MANOVA in terms of innovation competency and creative product after the experimental group and the control group took the subject, revealed that the mean of the innovation competency score and the creative product score were different at a significance level of 0.05. After studying, the experimental group demonstrated a higher innovation competency and creative product scores than did the control group at 14.68 and 6.13 respectively. This result supported hypothesis No. 2 as shown in Table 5. The scores with regard to innovation competency and creative product after both groups had taken the subject are illustrated as shown in Figure 4.

Table 2. Innovation Competency score of the experimental group and the control group before studying.

Group	$\bar{X}$	S.D.	t	p
The experimental group	46.48	6.55	1.616	0.113
The control group	49.60	7.09		

Table 3. The experimental group's Innovation Competency score before and after studying the subject.

Experimental group	$\bar{X}$	S.D.	t	t
After studying	60.40	4.98	9.005**	0.000
Before studying	46.48	6.55		

Note : ** $p < 0.01$

Table 4. One-way MANOVA Assumption Statistic Test.

Group	Statistic	Innovation Competency score	Creative Product score
Experimental group	$\bar{X}$	60.40	25.40
	S.D.	4.98	1.644
Control group	$\bar{X}$	45.72	19.27
	S.D.	4.79	3.138
Leven's statistics (p)		3.67 (0.70)	1.03 (0.31)
Box's M (p)		7.85 (0.06)	
Bartlett's $\chi 2$ (p)		19.62 (0.00)	

Table 5. The one-way MANOVA results of Innovation Competency and Creative Product scores after studying between the experimental group and the control group.

Independent Variable	Statistic	Value	Approximate F	p
Group	Pillai's Trace	0.795	91.121	0.000
	Wilks' Lambda	0.205	91.121	0.000
	Hotelling's Trace	3.877	91.121	0.000
	Roy's Largest Root	3.877	91.121	0.000

Tests of Between-Subjects Effects

Dependent Variables	SS	df	MS	F	p	Post Hoc
Innovation Competency score	2693.78	1	2693.78	112.726	0.000	1>2
Creative Product score	470.32	1	470.32	74.97	0.000	1>2

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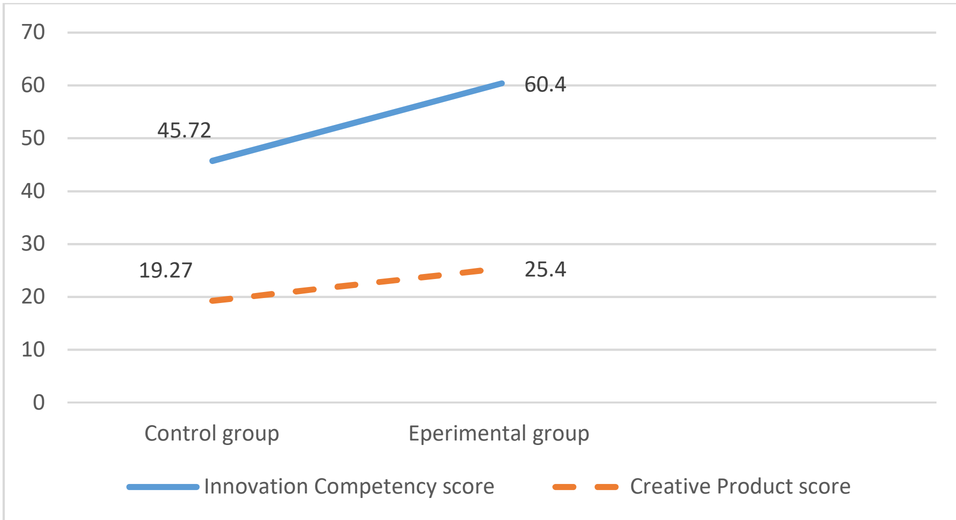

Figure 4. Innovation Competency score and Creative Product score

Hypothesis no. 3 : After studying, the experimental group had innovation competency scores more than the criteria (60 percent).

In terms of Hypothesis No. 3, the mean innovation competency score of the experimental group after studying was 60.40 with a standard deviation (S.D.) of 4.98, whereas the required criteria score of innovation competency was 39.60 (60 percent of 66 scores). Consequently, after studying the experimental group had a higher innovation competency score than the criteria at significance level of 0.05. Furthermore, after studying the subject, the experimental group had higher innovation competency scores than the criteria at 20.80. This complies with Hypothesis No. 3 as shown in Table 6.

Hypothesis no. 4 : After studying, the experimental group had creative product scores more than the criteria (60 percent).

In terms of Hypothesis No. 4, the mean creative product score of the experimental group after studying was 25.40 with a standard deviation (S.D.) of 1.64, whereas the required criteria score of creative product was 18.00 (60 percent of 30.00 scores). Consequently, after studying the experimental group had a higher creative product score than the criteria at significance level of 0.05. Furthermore, after studying the subject, the experimental group had higher creative product scores than the criteria at 7.40. This complies with Hypothesis No. 4 as shown in Table 7.

Table 6. The experimental group's Innovation Competency score after studying and the criteria.

Experimental group	$\bar{X}$	S.D.	The criteria	t	p
Innovation Competency score	60.40	4.98	39.60	20.87**	0.00

Note : ** $p < 0.01$

Table 7. The experimental group's creative product score after studying and the criteria.

Experimental group	$\bar{X}$	S.D.	The criteria	t	p
Innovation Competency score	25.40	1.64	18.00	22.50**	0.00

Note : ** $p < 0.01$

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Table 8. The results of the hypothesis 1-4.

Hypothesis	Results of hypothesis
Hypothesis 1 : After studying, the experimental group had higher innovation competency score than before studying.	Accept
Hypothesis 2 : After studying, the experimental group had higher innovation competency and creative product scores more than the control group.	Accept
Hypothesis 3: After studying, the experimental group had innovation competency scores more than the criteria (60 percent).	Accept
Hypothesis 4 : After studying, the experimental group had creative product scores more than the criteria (60 percent).	Accept

5. DISCUSSION

1. The overall assessment of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product was ranked as being at the highest. This was because the researcher had utilized transformative learning and digital fabrication laboratory theories as a guideline to create a learning model to enhance innovation competency and encourage creative output. This complied with concepts posited by Mezirow [17], Brock [36], Mayo [18], Sharpe [19], Beer [20], Jacobs [21], Yıldırım and Yelken [22], and Johnson and Olanoff [23] which stated that transformative learning was a learning method that involved critical reflection on new and diverse concepts. Transformative learning also supported the operational process of the digital fabrication laboratory according to the concepts proposed by Lewis and Clark [24], Hamid et al. [25], Lorenzo et al. [26], Lee et al. [8], Putro and Wirasmoyo [27], Soomro and Georgiev [9], Hsieh and Chang [10] and Formlabs [28], with the use of 4 tools: 1. hardware, 2. software, 3. materials, and 4. storage and simulator tools [6], [11], [22], [26], [29] the use of which encouraged students to develop innovation competency, which in turn led to creative innovation and output.

2. The reason why the experimental group had a higher mean innovation competency score after taking the subject compared with the score before taking the subject, was because the researcher integrated the process of transformative learning and digital fabrication which consists of 5 steps. Each step helped to develop students' innovation competency for them to be able to create creative product [17], [18], [19], [20], [21], [22], [23], [36] and the experimental group students were able to engage in practical work following the digital fabrication laboratory approach [9], [10], Formlabs [28], The experimental group could follow the digital fabrication laboratory guidelines and use all sorts of tools related to hardware, software, materials, storage, and simulator [11], [26], [30] to produce the creative product. This information was relevant to the study of Poltana et al., [37], Pitkanen and Andersen [38], Chan and Blikstein [39].

3. The experimental group had a higher mean innovation competency score and creative product scores than the control group because the experimental group had learned the transformative learning system with a digital fabrication laboratory to improve innovation competency and creative product, which was a learning system that included a process to encourage students to develop innovation competency through five transformative learning stages.: 1)Learning Change : TL1 2) Find a new conceptual framework : TL2 3) New Planning : TL3 4)Testing : TL4 and 5)Integrating new Competency and Perspectives : TL5 [17] [18], [19], [20], [21], [22], [23] , [37], with digital fabrication laboratory 4 process [9], [10], [28], and encouraged the experimental group to develop creative product using 4 types of tools in digital fabrication laboratory which were 1) hardware, 2) software, 3) material, and 4) storage and simulator [26], while the control group did not go through the process to raise the innovation competency. In addition, the control group did not have sufficient tools to produce creative product.

4. Hence, the experimental group had higher mean scores of innovation competency and creative product than the control group. The experimental group had a higher mean innovation competency score compared to the criterion, because the transformative learning system with digital

fabrication laboratory to enhance innovation competency and creative product was considered as the learning system that consisted of the processes to encourage students to develop innovation competency; which included creative problem solving, systems thinking, goal orientation, teamwork, and networking [32]. There were 5 stages of transformative learning; 1) Learning Change : TL1, 2) Find a new conceptual framework : TL2, 3) New Planning : TL3, 4)Testing : TL4, and 5) Integrating new competency and perspectives : TL5. Additionally, there were 4 steps of digital fabrication laboratory; 1) Design, 2) Prepare, 3) Fabricate, and 4) Assembly and Installation. Thus, the experimental group had higher mean score of innovation competency than the criterion. This was in line with the policy stated by the Southeast Bangkok College [40].

5. The experimental group had higher mean score of creative products that the criterion, because the transformative learning system with digital fabrication laboratory to enhance innovation competency and creative product was the learning system that encouraged students to develop creative product via the transformative learning process with digital fabrication laboratory and 4 tools in digital fabrication laboratory; 1) hardware, 2) software, 3) material, and 4) storage and simulator. These 4 tools were important for students to create creative product. Therefore, the experimental group had a higher mean creative product score than the criterion. This was consistent with the policy established by the Southeast Bangkok College [40], which encouraged students to practice what they had studied.

6. CONCLUSION

The system of transformative learning with digital fabrication laboratory to enhance innovation competency and creative product. The researcher developed using the concept of transformative learning to change thinking Students' perspectives and use of the digital fabrication laboratory to create product that is a teaching model that helps respond to Thailand's 'industrialization 4.0' era policy to develop students to be innovators in the future.

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