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Merging Design Thinking into Translational Research in a Biomedical Engineering Laboratory (DT-TRBEL) Course

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Abstract: Laboratory classes offered in universities often fail to develop students' ability to identify questions and encourage creativity to solve authentic problems. Lab exercises tend to provide clear step-by-step instructions, leaving little room for experimentation or creative thinking. Unfortunately, this approach can result in engineering students losing the skills they need to solve unprecedented challenges in their future professional careers. Biomedical engineering is particularly vulnerable to this training approach, given that students are taught to devise ideas to solve medical problems. To address this issue, the current study combined the curriculum designs of translational research and design thinking. This guided students in bringing biomaterials into the clinic and stimulated their interest in biomaterial development. The resulting course, called DT-TRBEL (Design-Thinking: Translational Research in Biomedical Engineering Laboratory Course), focuses on developing dental biomaterials, including material preparation, analysis, and cytotoxicity testing. The data was collected and evaluated through a survey of self-efficacy of creativity, student motivation, and learning scores of both the prerequisite course "Material Science" and DT-TRBEL. The study found that DT-TRBEL did not have a positive effect on overall motivation or the sense of self-efficacy regarding creativity. However, it did have a significant gender effect, benefiting female students more than male students. The discussion covers implementation and further directions for research.

Keywords: translational research; design thinking; laboratory course; STEM; creative self-efficacy

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1. Introduction

Laboratory courses should be created as a series of processes that encourage questioning, exploration, and verification [1]. However, in the current exam-focused teaching environment, the laboratory course design and teaching methods of most Taiwanese universities fail to spark students' interest in experimental design. Instead, these courses prioritize the teaching of experimental instrument usage and technical operations, while overlooking the development of students' independent thinking and data interpretation skills. Consequently, students may only gain familiarity with the experimental equipment and learn how to conduct experiments based on the correct procedures [2]. Furthermore, it's possible for students to overlook the details of the learning process and instead prioritize achieving high scores or memorizing standardized answers. However, if the course does not prioritize independent thinking and design processes, students may fail to see the connection between principles and experiments. This can lead to a lack of curiosity and a disinterest in using equipment to verify known experiments [3]. Therefore, there has been a continuous critique of high schools for placing insufficient emphasis on the cultivation of critical thinking and problem-solving abilities in their science curriculums [4].

Even in laboratory courses, exercises have been overly prescriptive, with clear step-by-step instructions that leave little room for experimentation or creative thinking [5]. The most pressing task of laboratory courses in universities is to educate students to apply what they have learned to new situations, particularly in the field of biomedical engineering [6].

The ultimate goals of education in this field are to produce more meaningful and applicable medical devices or materials that directly benefit human health [7]. In recent years, the biomedical engineering industry has faced criticism for the slow and expensive process of applying basic scientific research to practical clinical applications. The separation between research and clinical medicine has made it difficult for aspiring scientists to gain exposure to the complexities of human pathophysiology and to access clinical applications. To address this issue, the Howard Hughes Medical Institute at Chevy Chase, MD, USA, began supporting graduate programs that integrate clinical knowledge into biomedical training in 2005. The aim was to establish a clear path from laboratory research to practical clinical applications by breaking down the existing barrier between research and clinical medicine in this field [8].

The field of biomedical engineering is ever progressing. Translational research is one of the rapidly growing trends that involves collaboration between different fields of study. Its main goal is to speed up the process of turning scientific discoveries into new or improved methods of healthcare. This approach encourages the exchange of ideas and information between researchers in basic, preclinical, clinical, epidemiological, and health outcomes research areas. Thus, merging translational medicine into bioengineering laboratory courses encourages students to discover clinical value in basic laboratory research and apply it in clinical settings to solve medical problems. It encompasses fundamental principles of materials, formulations, manufacturing technologies, patent acquisition, and material biocompatibility. This concept covers the entire process from laboratory to clinical application. Five stages are included in translational research: (1) identifying the underlying mechanism of a health problem or disease; (2) analyzing preliminary research results to determine clinical effects and propose new diagnosis, treatment, or prevention methods; (3) identifying the ideal clinical conditions for the proposed treatment; (4) analyzing the clinical feasibility of the treatment method; and (5) final analysis of the impact of this inspection and treatment method on human health.

1.1. Practicing Translational Research (TR) via Design-Thinking (DT)

Design thinking gained popularity in the 1960s and is now widely used in product development, business, primary education, and medical research [9,10]. The process involves five stages: discovering empathy, defining requirements, creative brainstorming, prototyping, and testing [11]. It is a human-centered problem-solving approach that helps groups navigate ambiguity and find innovative solutions within traditional academic environments. The process starts with identifying people's needs and exploring their pain points and conditions from their perspective, then designing solutions that meet clinical needs. With this methodology, innovative solutions to various issues can be found, leading to more possibilities [12]. Although initially applied to the design of products and services, DT has recently been adopted in medical education to promote the development of new products by discussing medical issues [12].

By integrating design thinking into translational research, cross-disciplinary teams can be formed to advance translational research [13,14]. The path to addressing a complex problem is not linear and requires cross-disciplinary teams to approach complex problems with creativity and exploration [13]. However, in many engineering scenarios, universities may not have access to a clinical environment. This can result in reduced engagement and unclear research decisions or actions. To tackle these challenges, many turn to the fields of design thinking and human-centered design, aiming at creating immersive environments that foster collaborative brainstorming [15,16]. DT is a structured approach that allows students to combine creativity and innovation, and more importantly, it can help students understand the concepts of translational medicine more efficiently.

Based on the above rationale, it is argued that utilizing the DT strategy can better echo the procedure for TR while integrating the bioengineering learning materials into the laboratory learning settings. Incorporating real-world scenarios into class instruction allows students to apply learned concepts and put theory into practice. To foster students' independent thinking and reflection on the nature of scientific inquiry, we have proposed to combine DT and TR in the Biomedical Engineering Laboratory (DT-TRBEL) course.

1.2. Student Motivation and Creativity

Several facets of the design thinking process naturally overlap with factors that may enhance learning motivation and engagement [17], such as empathy as a motivational driver [18], prototyping and immediate feedback [19], etc. Motivational enhancement can foster an environment that encourages creativity in the Design-Thinking (DT) process. [20].

One's creativity or one's sense of creative-self has long been regarded as one crucial factor for the design-thinking process [21]. Although students' sense of creative self can be affected by their surrounding peers or society [22], it is increasingly found that one's belief in self-motivation can also promote their achievement in creative problem-solving procedures [23]. Within STEM education (i.e., learning subjects blended with Science, Technology, Engineering, and Mathematics), it is crucial to nourish students' sense of creativity through learner-centered instruction while analytical and divergent thinking skills are simultaneously and consistently practiced [15,16]. Further, it is in the same vein that design-thinking instructions and processes are aimed to facilitate students to come up with creative paths for solving problems [9,10].

To specify, creative self-efficacy (CSE) is defined as the faith in one's capability to achieve creative outcomes [24,25]. This faith can reflect one's pre-judgment toward his/her creativity. Consequently, it affects one's decisions to engage in activities that require creative design and the thinking of ideas, and eventually changes the potential for innovative outcomes. Various works have been conducted and documented CSE as a predictor, mediator, control/dependent variable, etc. [26].

CSE is not an incidental phenomenon of personality, prior performance, or other characteristics of individual differences. They are related to them and may develop under their influence. Still, they are not only independent but dynamically changing, and the literature points out that CSEs play a mediating role between creative potential and performance [24,25]. Therefore, researchers need to take a more integrated and dynamic approach when studying these beliefs [10,27,28]. Doing so requires a conceptual change in epistemological and methodological perspectives [29]. Epistemologically speaking, creative self-belief should be somewhere between trait and status, closer to motivational orientation than personality traits [30] and, methodologically, their development is complemented by the activities of the individual, the example of significant others, previous successes and failures, as well as cultural conditions and the influence of peers [29].

Therefore, creative self-efficacy (CSE) influences learning motivation and is related to the specificity of the task. Individuals may value creativity in general and consider themselves either creative or less creative. However, regardless of their level of CSE, individuals would constantly put forth effort toward their creative tasks if they wish to complete them; for example, a drawing assignment. While considering the dynamic characteristics of creative self-belief, it is suggested to take these self-estimates into consideration, but self-beliefs such as CSE would be more informative for analysis.

Thus, it is important to consider the connection between motivation and creativity. Research has shown that incorporating design thinking into engineering problem-solving courses can promote a sense of creative self-efficacy (CSE), while keeping learners motivated to learn [31]. For instance, by integrating design thinking into engineering problem-solving courses, students can boost their creativity and motivation. This approach helps students develop a stronger sense of creativity and self-efficacy, which is essential in maintaining their motivation levels throughout the course. By adopting a more innovative and imaginative mindset, students can effectively tackle engineering problems, thus enhancing their problem-solving skills, critical thinking abilities, and overall academic performance. Moreover, cultivating creativity and motivation in this manner may have benefits that extend beyond the classroom, such as increased self-confidence and a greater sense of personal fulfillment. Since design thinking is a process of collaboration and iteration used to solve complex, real-world problems that are often not well-defined [16], by engaging in design thinking, students can improve their ability to think creatively and work collaboratively, which can enhance their confidence in these areas.

1.3. Gender Effects in Engineering Education

Persistent gender imbalances in undergraduate STEM courses continue to be a central point of discussion among educators and policymakers. This disparity is particularly pronounced in fields like computer science and engineering, where women and other marginalized groups remain vastly underrepresented. Although initiatives aimed at rectifying this were introduced, such as the adoption of inclusive teaching methodologies and launching diversity-centric programs, progress has been incremental and inconsistent. In the study by Jagannathan and Komives [32], it was deduced that female students receive fewer opportunities to participate in class discussions compared to their male counterparts. This disparity might influence their self-assurance and perceived aptitude for roles during college training and their professional career. The same study also indicated that female students, on average, lagged behind in performance for subjects and necessitated supplementary resources to achieve parity. In contrast, other research established that, within the context of collaborative assignments, female students exhibited a proficiency on par with male students [33]. This is particularly found to be beneficial in the design-thinking enhanced environment for engineering learning [15,34].

In summary, the current study utilized the Biomedical Engineering Laboratory course as a platform to integrate design thinking into the process of translational research. This afforded students the opportunity to apply the five steps of design thinking towards their understanding of translational research. The course primarily focused on the development of dental biomaterials, which included material preparation, analysis, and cytotoxicity analysis. To evaluate the effectiveness of the DT-TRBEL (Design-Thinking Translational Research in Biomedical Engineering Laboratory Course) on student learning outcomes and motivation, this study conducted a survey that measured creativity and student motivation. In addition, the role of creativity and gender in the DT-TRBEL class were also examined. The following are the research questions to assist the present research.

1. Do relationships exist among variables of sense of creativity, motivation, and students learning performances of Material Science and DT-TRBEL?
2. Does the DT-TRBEL (Lab) class have an effect on students' learning performance, sense of creativity, and motivation?
3. Does gender have an effect on the current DT-TRBEL class?

2. Materials and Methods

The current course was developed based on the rationales mentioned above regarding the framework of design thinking and medical education, specifically in translational research for biomaterials. This following section describes our methodology

2.1. Integration of Design Thinking into the Translational Research in Biomedical Engineering Laboratory (DT-TRBEL) Course

This course focused on the development of dental biomaterials, covering material preparation, analysis, and cytotoxicity testing. The process followed the principle of translational research (TR), which helped students understand the flow of experimental design of TR. Furthermore, design thinking was integrated into the translational research process, allowing students to apply their knowledge of translational research to the five steps of design thinking: empathy, requirement definition, creative brainstorming, prototyping, and actual testing. Please see Table 1 for detailed DT alignment with the core concepts of TR.

Table 1. DT-TRBEL Course structure.

Weeks	Translational Research	Course Objective and Content	Technology Support	Design Thinking
1 to 2	Defines the underlying mechanism of a health problem or disease	Course introduction, grouping, clinical problem discussion, basic laboratory equipment training	Lectures	Empathize
3	Analysis of fundamental research results to determine clinical effects. And propose new diagnoses, treatments, or new prevention methods	Dental materials preparation, characterization, surface morphology, surface functional group, materials' setting time, mechanical strength, and materials' degradation rate analysis	XRD, SEM, FTIR, viscometer, universal testing machine, UV-Vis, etc.	Define
4	Analysis of the ideal clinical conditions for this treatment			Ideate
5 to 8	Analysis of the clinical feasibility of the treatment method			Prototype
9		Mid-term examination		
10 to 18	The final analysis of the impact of this inspection and treatment method on human health	Biocompatibility analysis	Cell culture incubator, biosafety cabinets, cells, culture medium, etc.	Test

2.2. Participants

This course is mandatory for students in the Department of Biomedical Engineering at Chung Yuan Christian University (CYCU) in Taiwan. It is worth noting that CYCU was the first university in Taiwan to establish a medical engineering department, which has produced the largest number of medical engineering alumni in the country. Students from the Department of Biomedical Engineering at CYCU participated in the current study. A total of 33 students, consisting of 15 males and 18 females, took the Biomedical Engineering Laboratory course. All of these students were juniors in the department who successfully completed the material science course as a prerequisite in the previous semester. This meant that they had a good understanding of material science.

While the material science course provided a theoretical foundation, the Biomedical Engineering Laboratory course was a comprehensive and practical application of the material science course, both of which were taught by the same instructor. Final grades in the Biomedical Engineering Laboratory course were determined based on assignments, oral and written reports, quizzes, and teamwork.

2.3. Procedures

The DT-TRBEL course focused on developing dental materials. This included materials preparation, characterization, surface morphology, surface functional group analysis, materials' setting time analysis, mechanical strength analysis, materials' degradation rate, and biocompatibility analysis. The course was conducted in small groups, with eight groups of about 4 to 5 people each. Four teaching assistants were available to assist each group with the experiment. The primary material for the experiments in this course was hydroxyapatite (HAp). HAp is a key component of bones and teeth and has many medical uses. The course covered how to prepare, analyze, and test the cell toxicity of HAp materials, as previously described [35].

The main lab project for every group was to utilize a wet chemical method to produce HAp with a $Ca_{10}(PO_4)_6(OH)_2$ formula. Specifically, they added a 0.3 M H_3PO_4 solution to a 0.5 M $Ca(OH)_2$ solution with a Ca/P ratio of 1.67, stirring the mixture at 80 °C for 2 h and maintaining a pH of 8.0. Next, the mixture was centrifuged, washed, and freeze-dried for further analysis. Finally, X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), ultraviolet-visible spectroscopy (UV-Vis), a viscometer, and universal testing machine were used to analyze the crystal structure, shape, functional groups, concentration, stability, and setting time of the HAp materials, respectively. Students also conducted an invitro biocompatibility test of HAp using 3-(4,5-

Dimethylthiazol-2-yl)-2,5-Diphenyltetrazolium Bromide (MTT) assay in accordance with ISO-10993. Please see Table 2 for a summary.

Table 2. The major lab project of the DT-TRBEL course.

Process	Method
Production of HAp	Wet chemical method
Chemical formula of HAp	$Ca_{10}(PO_4)_6(OH)_2$
Reactants	0.3 M H_3PO_4 and 0.5 M $Ca(OH)_2$ with a Ca/P ratio of 1.67
Temperature and time	80 °C for 2 h
Maintained pH	8
Analysis methods	X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), ultraviolet-visible spectroscopy (UV-Vis), viscometer, and universal testing machine
Properties analyzed	Crystal structure, shape, functional groups, concentration, stability, and setting time of HAp materials
Biocompatibility test	In vitro using 3-(4,5-Dimethylthiazol-2-yl)-2,5-Diphenyltetrazolium Bromide (MTT) assay in accordance with ISO-10993

The lab process is designed mainly according to the concept of translational research. Through complete experiments, from material preparation and analysis to cell experiments, students can understand the development process of materials. Guest speakers from medical school were invited to provide lectures that helped students understand clinical needs. The merger of translational research and design thinking allowed for exploration of the fields of human-centered design and design thinking, with the goal of creating immersive environments that promote collaborative brainstorming. (Please see Table 1). Through this process, students can redefine the clinical significance of dental materials (HAp) through group discussions, literature searches, and experimental procedures.

To evaluate the student's learning effectiveness, Group discussions, mid-term tests, mid-term and final oral reports, and experimental record reports from the courses of materials science and bioengineering experiments were utilized. Since "material science" serves as the foundation for "bioengineering laboratory", it is noted that students took "material science" and "bioengineering laboratory" in successive semesters. Those students who took "material science" would mostly take "bioengineering laboratory" in the following semesters. Thus, the participants' consequent attitude and performance data could be collected. Please seen Figure 1 for overall experimental design of the current study.

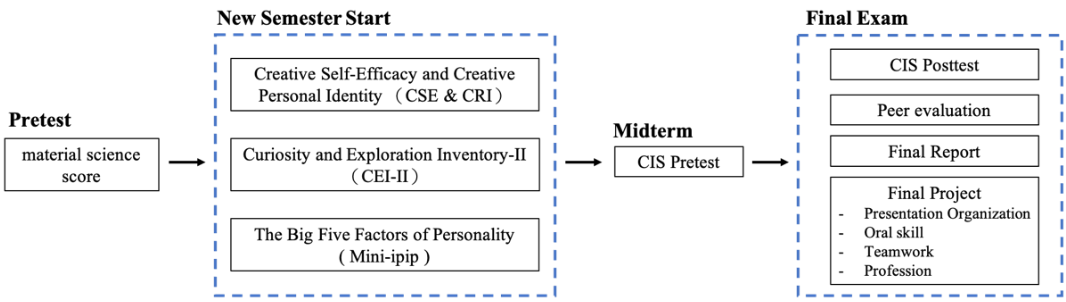

Figure 1. Flowchart of the experimental design of the present study.

2.3.1. Motivation Survey (ARCS)

The ARCS motivational model is one of the most adopted instructional models proposed by Keller to assess attitudes toward learning [36]. Four dimensions are included in the scale: Attention, Relevance, Confidence, and Satisfaction, wherein attention assesses the learner's levels of interest and attention is held by the instruction; relevance assesses the levels of the learner's perceived usefulness toward the subject to be learned; confidence assesses learner's estimated levels of the probability to be successful in the course; satisfaction assesses learner's levels of satisfaction about what they are to achieve. The

ARCS motivational model is supported by two instruments: CIS (I.e., course interest survey, measures learner's responses to instructor-led instruction) and IMMS (I.e., instructional materials motivational survey, measures learner's responses to self-directed instructional materials). CIS was adopted for the current study. The CIS reliability is reported as (in Cronbach's Alpha) 0.95 (total scale), 0.84 (Attention), 0.84 (Relevance), 0.81 (Confidence), and 0.88 (Satisfaction). Therefore, the ARCS motivation model evaluates how students might respond to the DT-TRBEL course regarding their overall motivation and the four dimensions that composite their perception of the course.

2.3.2. Short Scale for Creative Self (SSCS)

The Short Scale for Creative Self (SSCS) scale was adopted, which includes creative self-efficacy (CSE), 6 items, and creative personal identity (CPI), which includes 5 items developed by Karwowski and his colleagues [37]. The present study tested its reliability with Cronbach's Alpha and retrieved the value of 0.97, suggesting good reliability of the CSE instrument. Example questions: I know I can efficiently solve even complicated problems; I trust my creative abilities; compared to my friends, I am distinguished by my imagination and ingenuity, etc.

3. Results

The following outcomes of the current study are presented aligned with the research questions.

RQ 1. Do relationships exist among variables of sense of creativity, motivation, and students learning performances of Material Science and DT-TRBEL?

In response to RQ 1, a preliminary correlation analysis was conducted. (Please see Table 3). Pearson correlation matrix revealed positive relationships on pre-Motivation survey vs. pre-SSCS, post-Motivation survey vs. post-SSCS, and Material Science score (pre-knowledge), and DT-TRBEL(Lab) Score.

Table 3. Pearson correlational matrix.

		1	2	3	4	5	6
1.	Pre-Motivation	1	-	-	-	-	-
2.	Post-Motivation	0.637 **	1	-	-	-	-
3.	Material Science(MS)	−0.065	−0.012	1	-	-	-
4.	DT-TRBEL(Lab)	0.047	0.120	0.728 **	1	-	-
5.	Pre-SSCS	0.416 *	0.385	−0.389	−0.352	1	-
6.	Post-SSCS	0.371	0.444 *	−0.039	0.078	0.386	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

The matrix suggests that students with higher motivation entering the class could carry higher levels of perceived creative self-efficiency. Those who identify themselves with relatively higher creativity might hold better motivation prior to joining the next class (i.e., the DT-TRBEL class). Interestingly, it might be the same group who did not perform better in the prerequisite course (i.e., the previous material science class). Although our analysis did not tend to compare the final scores of MS and DT-TRBEL directly, students showed a more consistent performance on the final scores with relatively large effect size (i.e., $M_{DT\text{-}TRBAL}$ = 83.36, $SD_{DT\text{-}TRBAL}$ = 5.36 to M_{MS} = 75.58, SD_{MS} = 13.54; Cohen's d = 0.76).

RQ 2. Does the DT-TRBEL (Lab) class have an effect on students' learning performance, sense of creativity, and motivation?

For detecting the changes on students learning performance and motivation, a series of *t*-tests were conducted. At first, the set of paired *t*-tests showed no significant difference in students' overall motivation in comparing the post-survey to the pre-survey, suggesting that students did not reveal different learning attitudes toward the DT-TRBEL class. (Please see Table 4)

Table 4. Paired *t*-test table of learning outcome and motivation with sub-dimensions of ARCS.

Item	Mean	SD	*t*-Test
Motivation-pre Motivation-post	32.61 32.43	4.06 4.47	0.25
A-pre A-post	31.58 30.88	4.61 5.03	0.87
R-pre R-post	34.96 33.13	3.94 5.03	2.18 *
C-pre C-post	29.63 30.42	3.56 4.09	−1.10
S-pre S-post	34.29 35.29	5.20 5.13	−0.89
MaterialSci LabFinalScore	75.58 83.36	13.54 5.36	−3.70 **

* $p < 0.05$, ** $p < 0.01$ significance level.

However, it is worthwhile to point out that a significant drop in relevance was found among the subdimensions of attention, relevance, confidence, and satisfaction. In the ARCS motivational model: attention: capturing and maintaining learners' interest in effective learning; relevance: bridge theory and real-world applications; confidence: developing success expectations vital for learners to control their learning process; and satisfaction: satisfying with learning outcomes and fulfilled with achievements.

Next, due to the form of student performance evaluations on Material Science and DT-TRBEL were different, it was not statistically comparable. Moreover, according to the result of RQ1, higher pre-SSCS could lead to higher learning performance. Therefore, the sense of creative self-efficacy (pre-SSCS) was used as a grouping criterion for analyses (see Table 5). As a result, the overall class setting of DT-TRBEL did not have an effect on student performance while grouping the participants into high- and low- creative self-efficacy. Similarly, the "relevance" sub-dimension of motivation and overall motivation were affected by their self-identification on creativity.

RQ 3. Does gender have an effect on the current DT-TRBEL class?

Table 5. *T*-tests concerning group setting of high- and low-creative self-efficacy (SSCS).

Item	t	df	Sig. (2-Tailed)
DT-TRBEL	−1.53	22	0.14
Post-SSCS	1.60	22	0.12
Post-Motivation	2.23	22	0.03 *
Post-A	1.98	22	0.06
Post-R	2.48	22	0.02 *
Post-C	1.86	22	0.08
Post-S	1.84	22	0.08

*. Correlation is significant at the 0.05 level (2-tailed).

When analyzing whether gender has an effect on students' learning outcomes, motivation, and self-creativity, it was found that gender and self-efficacy in creativity have an impact on the overall learning performance score in the DT-TRBEL course. Please see Table 6 for gender-related descriptive statistics.

Table 6. Descriptive statistics on the grouping of gender.

	Gender	N	Mean	Std. Deviation
Motivation-re	Male	15	32.58	4.43
	Female	9	32.67	3.61
Motivation-post	Male	15	33.23	4.60
	Female	9	31.08	4.16
SSCS-pre	Male	15	43.60	7.93
	Female	9	38.89	8.27
SSCS-post	Male	15	42.27	7.04
	Female	9	41.56	12.06
LabFinalScore	Male	15	81.63	5.64
	Female	9	86.24	3.48
MaterialSci	Male	15	70.80	13.29
	Female	9	83.56	10.15

Female students have demonstrated an overall higher level of learning outcomes than male students. Interestingly, male students seemed to demonstrate higher creative self-efficacy than female students from the beginning to the end, and female students slightly gained self-efficacy, while performing significantly higher than male students both in Material Science and DT-TRBEL courses. Please see Table 7 for results of *t*-test concerning gender effects.

Table 7. *T*-tests concerning group setting of gender difference.

	t	df	Sig. (2-Tailed)
Pre-Motivation	−0.05	22	0.96
Post-Motivation	1.15	22	0.26
Pre-SSCS	1.39	22	0.18
Post-SSCS	0.18	22	0.86
$\text{Score}_{\text{DT-TRBEL}}$	−2.20	22	0.03 *
Score_{MS}	−2.47	22	0.02 *

*. Correlation is significant at the 0.05 level (2-tailed).

The correlational matrix and the gender effect may depict those (female) who performed better in the prerequisite class (material science) also outperformed their peers (male) in the lab class.

4. Discussions

4.1. Effects regarding Design Thinking Integration

Although the learning outcome improved, students revealed a lower level of practicality perceived from the DT-TRBEL class. There might have been several reasons that resulted in a more serious attitude of the students toward the relevance of this class. Due to its complexity and cost, translational research in biomedical engineering has not been widely implemented as instructional material in undergraduate lab classes. The current study utilized design thinking as an unconventional approach, allowing students to create solutions for authentic biomedical and clinical problems.

However, they might still require more real-world job experience later in their "actual" career. As they are in a real job setting (i.e., in the research and design division), they would obtain authentic experience about what resources and tools they can use to turn ideas or products into actual projects and production. It might be one of the reasons for them to lose the belief of how to "bridge the theory they learn with the real-world applications". In fact, a design-thinking approach did shorten the gap for them to actually "practice their imagination to solve real-world problems" (e.g., as they presented their final projects) in the lab setting in the current study.

For RQ2, the final score of DT-TRBEL did not relate to either the pre- or post-SSCS, suggesting no observable trends among these factors. To see whether the beginning status of students' creative self-efficacy affects the DT-TRBEL course performance, the pre-SSCS was utilized and separated students into high and low SSCS groups. As a result, DT-TRBEL final scores still do not differ among the students, suggesting that creative self-efficacy does not affect a design thinking process for learning in such biomedical engineering design thinking class. This finding has an implementation for incorporating DT into current STEM education.

Previous studies have observed similar results wherein design thinking might not necessarily improve students' creative self-efficacy [9,38]. Enhancing students' capacity for "industrial engineering" idea generation is notably achieved through the design-thinking process; however, it does not necessarily foster their skills in assessing the relevance or effectiveness of these ideas for specific tasks and may sometimes impede that ability [39]. In a different discipline in technology-emphasis, students learning AI utilized design-thinking-boosted AI application creativity, particularly in originality, value, functionality, and elaboration. In contrast, material innovation, aesthetics, idea organization, and overall product creativity showed no significant differences [40]. Along those courses, students' skills for creativity idea generation, problem-solving skills, and design-thinking skills were improved [41,42].

4.2. Gender Effects

To illustrate, the DT-TRBEL course integrated with the component of design-thinking activities seemed a particularly positive treatment for female biomedical engineering students. After the laboratory portion was completed, there was the DT translational research class activity. Female students seemed to respond better to the procedures of DT, wherein a creative environment was encouraged for idea generation about promoting their products of translational research as the course project. This result is consistent with a similar setting in a DT engineering course approach, wherein female high school students had gained a notable achievement [33]. Although scholars have pointed out the underrepresentation of women in the field (or career) of STEM (i.e., science, technology, engineering, mathematics) or learning with such an engineering subject similar to the DT-TRBEL course, studies have proven that female learners could outlearn their male peers, but less could retain their academic major or career in STEM [43–45]. The reasons remain complex due to social justice, political and economic background, and beyond [46]. In some social contexts, female individuals may experience different values from their society, which may cultivate an atmosphere of decreasing confidence, job expectation, encouragement for pursuing STEM careers, etc. [47].

It is conjectured that females' human nature may tend to show more empathy for the needs of surrounding people than males, which may be another reason for them to feel more comfortable with the DT procedure than their male peers. As a result, being creative in empathy for human needs for biomedical production can be encouraging for female students. The more learning interest that grows, the more confidence to create and design [15]. However, these male biomedical major students seemed to perceive a higher level of motivation from the DT-TRBEL setting, but this was not significant. Perhaps the course design was relevant to their professional learning and effectively related to skills needed in their future career. Although they were valued more on the course than females, there might be more obstacles to learning such a subject.

There might have been more factors interfered with the 18-week length of the course (e.g., group settings, hands-on learning activities, etc.). Although the experimental process of translational medicine is standardized (i.e., the laboratory experiments follow strict steps) and requires a material science foundation as prerequisite knowledge, the course followed the results of the translational medical process, supplemented by way of creative thinking (i.e., DT), and the practice of the experimental results of the process of translating medicine into creative production altogether empowered those low achievers in the prerequisite course to outperform their counterparts in the DT-TRBLE course. It is also noted that some students may obtain more confidence in a learning-by-doing situation, as it is the nature of the laboratory setting. Additionally, in the subsequent lab course, students could recall and practice the knowledge they had learned (or had not learned well) from Material Science.

5. Conclusions

The present study sought an instructional strategy to improve the learning experience of one laboratory course of biomedical engineering with the integration of design thinking as the core procedure, DT-TRBEL. As a result, it was found effective on student motivation but not on the Lab final score between high-low SSCS groups while controlling for the prerequisite course score as the covariate (i.e., Material Science score). Among the motivational dimensions, "relevance" was significantly affected by the treatment. SSCS (creative self-efficacy) was positively correlated with motivation in this course. When considering a gender effect, females outperformed males in the Material Science and DT-TRBEL courses.

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