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Interdisciplinary Critical and Design Thinking*

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Despite the importance of design thinking, there has been little research on interdisciplinary augmentation and the clear articulation of cognitive domain effects is still missing. The present study explores students' perceptions of and experiences in critical thinking and students' creative design ability in different study disciplines and explores correlations between students' attitudes and beliefs towards critical thinking and their design thinking ability. A sample of 268 students aged 21–23 years was collected. The students' majors include preservice technology and engineering teachers' education, chemical engineering, electrical and computer engineering, and mechanical engineering. For all subjects, critical thinking and design thinking are considered important interdisciplinary capabilities. Our findings suggest that the students' critical thinking might markedly affect their creative design ability. The ways in which each discipline is taught can be transferred across different knowledge and skill domains. We found that the most creative designers are mechanical engineering students, especially in terms of the originality and usefulness of design, while their divergent thinking ability might be improved with methods used in technology and engineering teacher education. Electrical and computer engineering students can benefit when interdisciplinary methods for improving understanding are applied as evidenced by the chemical and mechanical engineering curriculum. We also suggest that female students, who dominate in divergent thinking and critical thinking, might improve team learning and decision-making where transferable skills can be enhanced along with pedagogical content knowledge. These findings have implications for interdisciplinary innovation learning and creative design assessment.

Keywords: critical thinking, design thinking, interdisciplinarity, creative design ability, correlation analysis

1. Introduction

We are surrounded by many complex and rapidly changing issues that cannot be solved with technological knowledge alone. Society therefore needs very competent problem solvers to solve problems and improve our living environment [1]. Additionally, market competition dictates new needs and requires an improved ability to survive in a highly technological knowledge-based society. Innovativeness has been found to be a key competence for the sustainability and success of individuals and organisations [2]. Educators and engineers play important roles in encouraging innovation by companies and research-and-development institutions and in education [3]. Education is crucial to promoting the creative and innovative thinking of engineering students, but many engineering students do not display abilities in creative problem solving. Engineering curricula therefore need to foster problem-solving abilities from an interdisciplinary perspective, leading to innovation within design as a central activity of engineering [3]. Educators need to focus on teaching students how to critically analyse, conceptualize, and synthesize knowledge to cope with real-world problems and to identify competitive opportunities [4].

Traditional disciplinary academic teaching is based on a set of activities previously prepared by instructors and based on disciplinary content knowledge. Teachers usually orally transmit knowledge and students must acquire the knowledge. Students are therefore mostly passive listeners. Teachers have to encourage cooperative and collaborative work among students to improve learning, knowledge creation, and decision making [5]. Uziak, Komula, and Becker [6] presented the benefits of active learning methods used by different educators (e.g., John Dewey) for over 100 years. Uziak et. al. [6] have reported an improvement in students' attitude towards active methods of learning, more precisely towards problem-based learning. Students have commented that problem-based learning provides a good experience for analytical and logical thinking in problem solving, enriches their ability to learn, and increases their potential to think critically [6]. However, in a highly technologically developed world, important skills are teamwork, communication, problem solving, and critical thinking [7]. People are confronted with complex problems and they have to make rational decisions on the basis of evaluation and critical thinking rather than to passively accept solutions provided by others [8]. Dealing with difficult situations can help students learn design thinking [9].

Creativity and innovativeness have been found to

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be a key competence for the sustainability and success of individuals and organisations [2]. Nowadays, the numbers and complexities of problems and opportunities are growing rapidly. We therefore need problem solvers and problem seekers with expertise to find and solve problems and thus improve and sustain our social, economic, and physical environments.

Critical thinking, as a higher-order thinking process, is needed for individuals to become more acceptable, flexible, and able to cope with rapidly evolving information and thus make intelligent and rational decisions in dealing with personal, social, and scientific-technological problems; i.e., people need to be able to use various multidimensional higher-order thinking skills [10]. Critical thinking is taught differently in different disciplines of study. Critical thinking is generally affected by the context and discipline but it is also a transferable skill. The developed disposition of critical thinking might allow the transfer of knowledge, skills, and attitudes between different study disciplines. There is a need to optimize the learning of critical thinking skills in all disciplines as demonstrated in [11]. We should be able to use various multidimensional higher-order thinking skills in making intelligent and rational decisions when solving personal, social, and scientific-technological problems [12].

Design thinking has long been rooted in architecture and engineering but has now spread to other disciplines where it plays an important role. Design thinking might be a new trend and tool for interdisciplinary augmentation because it is closely related to innovation learning [13] and its applicative value is frequently discussed in both design and management circles. A course on design thinking might enhance interdisciplinary skills where enrolled students from different majors e.g., science, technology, engineering, business, and art, explore content and solve problems by integrating different learning approaches and methods. By allowing design activity, gaps in the students' knowledge, skills, and attitude towards design can be bridged and the students' innovative ability improved [13].

Technology and engineering teacher education: Instructors are important to the implementation of the design thinking process in the classroom. The instructor's knowledge dictates and affects students' learning [3]. Nowadays, teachers are increasingly challenged to be creative in novel practice; therefore, teacher education, based on design thinking, is important [14]. Technology and engineering teachers nowadays have to avoid the simple transfer of knowledge of materials, mastery of special technical skills and techniques, and correct use of instruments. The instructor gains more confidence in teaching and transferring knowledge by developing subject knowledge and pedagogical content knowledge (PCK). PCK refers to the transformation of different knowledge domains into a new and unique domain. PCK consists of knowledge of the students' concepts of technology and knowledge of their pre-and misconceptions related to technology, knowledge of the nature and purpose of technology education, and knowledge of approaches and teaching strategies for technology education [3].

Mechanical engineering education: Design thinking is seen as useful in uncovering the creative potential of students [2, 15]. Design is the central activity of engineering, and engineers need to be able to apply engineering design to solve problems [16]. Engineering is a problem-solving process and is associated with searching for technological solutions to practical problems and satisfying customer needs. Engineering focuses on analysis, synthesis, and convergent and divergent thinking [2]. Mechanical engineering students are surrounded with active forms of learning throughout their studies and combine practice and theory, laboratory work and coursework, and simulations and experimentation. They place much emphasis on testing the mechanical properties of materials and construction [17], where the importance of critical thinking and design thinking is seen.

Electrical and computer engineering education: The work of students focuses on algorithms, abstract thinking, and visualization of the problem to find the solution to the problem. The problem-solving strategy is an essential principle of computer science [18] while electrical engineering students develop procedural schematic knowledge and visualisation skills while working with wiring diagrams, schematics, and circuit drawings. There are several skills that every embedded engineer must have, e.g., vertical in-depth knowledge, be an all-rounder, networking, staying attuned with the latest technologies, project management skills, troubleshooting skills, and creativity [18].

Chemical engineering education: Chemical engineers are exposed to metacognitive prompts relating to macroscopic, microscopic, representative (symbolic), and descriptive processes and graphing skills [19]. The dominant activity of chemical engineers is investigation and empirical inquiry where apply chemistry, biology, physics and math to solve problems. Creative thinking, including divergent and convergent thinking, is essential in constructing explanations and developing solutions. Education is focused on active learning, especially inquiry-based learning, and many laboratory activities [20].

The global society faces enormous social, political, economic, and environmental challenges, all of which require creative responses. The problems that we face and the opportunities that arise arguably require all our creative thinking. It is not clear if current education charged with the transfer of knowledge, skills, attitudes, and values can cope with large-scale problems and opportunities, especially where study disciplines seem unprepared for an evolutionary leap forward in a person's capacity to think about the big picture. Moreover, there is evidence that deepening expertise can result in dogmatism, preventing the enhancement and effective use of a person's intelligence and gifts. Ambrose [21] argued that combining insights from diverse disciplines can enhance creative intelligence and combat dogmatism and thus accelerate the evolution of our abilities for conceptualisation with parallel improvement of our metacognition.

We address the following research questions against the background described above.

- What are the perceptions of and critical thinking experiences of students with different academic majors?
- What are the differences in creative design ability across study disciplines?
- What is a predictive value of students' critical thinking as part of their creative design ability?

The present study explores how the critical thinking of students in different disciplines synergizes with their creative design ability and how specifics of the discipline create an augmentation needed for design innovation.

2. Design Thinking as a Tool for Promoting Creative Design and Critical Thinking

Design thinking is generally defined as an analytic and creative process that engages a person in opportunities to experiment, create, and prototype models, gather feedback, and redesign [22, p. 330]. The design thinker can be described with numerous characteristics, such as human – and environment-centred concerns, the ability to visualize, a predisposition toward multifunctionality, systemic vision, affinity for teamwork, and the tendency to avoid the necessity of choice. Additionally, a good designer should be able to use different problem-solving strategies and choose the one that best meets the requirements of the situation [22]. A visual representation in design is viewed as a transaction between conceptual knowledge and visual knowledge [23]. Design offers opportunities for creativity because of the emergence of ill-defined problems, for which there is a variety of solutions and pathways to the solutions, and avoids pre-specified correct solutions [15]. Design thinking is a user-centric approach to problem solving and covers understanding (gathering problem-related information), observation (better understanding the problem), the point of view (analysing the preceding observations), visualization (brainstorming outline solutions to identify challenges), prototyping (creating the solution), and testing and reiterating (getting feedback on prototypes and modifying the prototypes as required) [2].

There are several definitions of creativity in the literature. Charyton et al. [24] defined creativity as the generation of new ideas, or new ways of looking at existing problems and seeing new opportunities. Cropley [2], in contrast, defined creativity as the creation of technical solutions for given problems. Creativity plays an important role in problem-solving activities through the comparison, evaluation and assessment, choosing, combining, and use of knowledge and skills in relation to usability to reach a practical solution [5]. Guilford [2] described creativity as problem solving and defined four stages: (1) recognition that a problem exists, (2) generation of a variety of relevant ideas, (3) evaluation of the various possibilities produced, and (4) drawing of appropriate conclusions that lead to the solution of the problem. From these phases, it is evident that creativity requires both divergent and convergent thinking. Esjeholm reported four criteria for identifying creativity in the domain of design [25].

- Conceptual creativity (the concept or idea): Has the designer proposed a concept that is original, novel, feasible, and useful and will function?
- Aesthetic creativity: Has the designer made proposals about those features of the product that will appeal to the senses; e.g., sight, hearing, touch, taste, and smell?
- Technical creativity: Has the designer proposed how the product will work and the nature of the components and materials required?
- Constructional creativity: Has the designer proposed how the product will be constructed and the tools and the processes needed?

Atkinson [26] argued that creativity is an intrinsic human trait and is a skill that can be taught and nurtured through working with problem solving strategies. Engineering design has an unleashed potential of stimulating students' higher-order thinking, where critical thinking plays a central role in learning [27]. Critical thinking is described as a metacognitive process comprising different sub-skills, such as analysis, evaluation, and inference [10]. Critical thinking is also a higher-order thinking skill, and a higher-order thinking process is not possible if one does not have enough knowledge [28]. Critical thinking is also an important skill in social and interpersonal contexts where good decision-making and problem-solving skills are needed

[2]. Halpern [28, p. 6] described critical thinking as the "use of those cognitive skills or strategies that increase the probability of a desirable outcome. It is used to describe thinking that is purposeful, reasoned, and goal directed – the kind of thinking involved in solving problems, formulating inferences, calculating likelihoods, and making decisions, when the thinker is using skills that are thoughtful and effective for the particular context and type of thinking task.'' Critical thinking is often referred to as a higher-order cognitive skill that involves analysis, synthesis, interpretation, evaluation, and noticing assumptions. However, the ability to think critically about specific information depends on recalling and understanding [28]. The most appropriate methods of developing critical thinking skills are collaborative methods with some teacher intervention. The role of the teacher is predominantly to motivate and encourage students to critically think during teamwork. Students have higher levels of trust in critical thinking when supported by teachers [27]. Furthermore, learning activities used to promote critical thinking must be designed in such a way as to facilitate transfer learning, so students are better prepared for unknown future challenges [28]. Halpern [28] presented a model for teaching critical thinking that has four parts: (a) a dispositional component that comprises modelling critical thinking and actively encouraging thoughtful responding; (b) instruction in and practice with critical thinking skills; (c) structure-training activities designed to facilitate transfer across contexts; and (d) a metacognitive component, which includes having students discuss the process of thinking.

Design thinking is a problem-solving approach that has been taught in informal and formal education settings across various disciplines globally [29]. Design thinking requires curiosity, imagination, and creativity to generate, explore, and develop possible solutions [29], and it might also depend on the skill level of critical thinking [29]. Furthermore, critical thinking and creative thinking are complementary processes [28]. As a creative approach, design thinking has become an evolving field in higher education, connecting students of various disciplines to solve complex problems as a team [13]. Higher-education institutions incorporate design thinking in the undergraduate curriculum, thereby exposing non-design students to design thinking skills [3, 13, 14].

3. Methodology

3.1 Sample

The sample in this study comprised 268 undergraduate students from Slovenia (University of Ljubljana) and Poland (Cracow University of Technology) in different higher-education disciplines, as listed in Table 1. The participants were aged between 20 and 23 years and comprised 145 females (54.1%) and 123 males (45.9 %).

3.2 Instrumentation

A modified test for creative design assessment (CEDA) was adopted to assess the creative design ability of students [24]. Participants were asked to resolve by sketching three design problems that incorporate one or more three-dimensional objects. Additionally, participants had to provide descriptions and list materials as well as identify problems that the design solves and list the potential users. Participants were to generate up to two designs per problem. The total time for the assessment was 30 minutes for the three problems or about 10 minutes per problem. Creativity includes *problem solving* (i.e., finding a solution to a specific problem) and *problem finding* (i.e., identifying other potential problems) and CEDA is a tool that assesses both dimensions. Problem finding was assessed in terms of identifying other uses for the design. Problem solving was assessed in terms of deriving a novel design to solve the problem posed. CEDA assesses both *convergent thinking* (i.e., generating one correct answer) and *divergent thinking* (i.e., generating multiple responses or answers). Convergent thinking was assessed in terms of solving the problem posed. Divergent thinking was assessed in terms of generating multiple solutions. *Constraint satisfaction* was also assessed, where students used shapes and materials within the parameters of the design. Additionally, CEDA assesses *fluency* (i.e., the number of ideas), *flexibility* (i.e., categories of ideas, types of ideas, and grouping of ideas), *originality* (i.e., new ideas and novelty), and *usefulness* (i.e., the practicality of a design based on the

Table 1. The number and percentage of students among different higher education disciplines

Study discipline	**Number [*N*]**	**Percentage [%]**
Technology and engineering teacher education	61	22.76
Chemical engineering	61	22.76
Electrical and computer engineering	60	22.39
Mechanical engineering	86	32.09

reliability, number of purposes, and number of applications both present and new) [24].

Participants were scored from 0 to 10 for each design problem according to *originality* and from 0 to 4 for each design problem according to *usefulness* [24]. The *fluency* and *flexibility* of design concepts were assessed for a number of items.

Cronbach's alpha for the sample in this study indicates that a test CEDA has moderate reliability of 0.86.

The 27-item Critical Thinking Toolkit (CriTT) was used to survey student attitudes and beliefs about critical thinking [27]. CriTT has the following factors.

- *Confidence in critical thinking* –17 items measure the participant confidence in critical thinking.
- *Valuing critical thinking* – Six items measure the extent to which students recognise the importance of critical thinking.
- *Misconceptions* – Four items measure the avoidance of critical thinking or misconceptions of critical thinking.

A 10-point Likert scale was used for assessment, with scores ranging from 10 for strong agreement to 1 for strong disagreement.

Internal consistency was analysed using Cronbach's alpha. The items in *Confidence in critical thinking* demonstrated high reliability (Cronbach's α of 0.90). The items in *Valuing critical thinking* and *Misconceptions* demonstrated moderate reliability (Cronbach's α of 0.81 and 0.76 respectively).

3.3 Data Collection and Analysis

The study was performed for the academic year 2018/2019. Before completing the questionnaire and test, students were briefed about the study and ethical considerations. The CEDA was administered when the critical thinking questionnaire had been completed. There were no time limits imposed on participants completing the critical thinking questionnaire, while the CEDA test was limited to 30 minutes.

The data were analysed using IBM SPSS (v.22) software. Cronbach' alpha coefficient was used to support the reliability of tests. Additionally, basic tools of descriptive statistics were used to present the student basic information, and the mean scores of dependent variables, analyses of variance, and multiple regression analysis were adopted to find and confirm significant relationships between groups.

4. Results

4.1 Students' Attitudes and Beliefs Towards Critical Thinking

The critical-thinking questionnaire measured the students' beliefs and attitudes about critical thinking on three subscales: *Confidence in critical thinking*, *Valuing critical thinking*, and *Misconceptions*. The scale of *Misconceptions* is reversed, which means that lower scores indicate a better understanding of misconceptions.

Fig. 1 shows differences across gender. Students perceived critical thinking as beneficial for good performance in higher education. Female students scored higher (as expressed by the mean *M* and standard deviation *SD*) than males in *Confidence in critical thinking* and *Valuing critical thinking* (M_f = 7.30, SD_f, = 1.09, M_m = 6.88, SD_m = 1.05; M_f = 7.49, SD_f, = 1.41, M_m = 6.8, SD_m = 1.40 respectively). Male students had a more developed understanding of misconceptions than female students (M_f = 6.25, SD_f, = 1.84, M_m = 6.03, SD_m = 1.68). The test for the homogeneity of variance was not significant (p > 0.05). There were significant differences for the subscales of *Confidence in critical thinking* (F = 10.35; df = 1; p = 0.001) and *Valuing critical thinking*

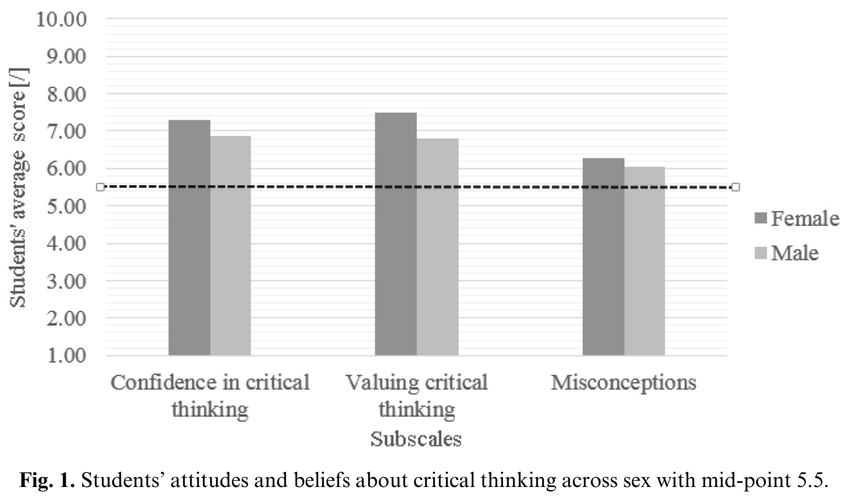

Fig. 1. Students' attitudes and beliefs about critical thinking across sex with mid-point 5.5.

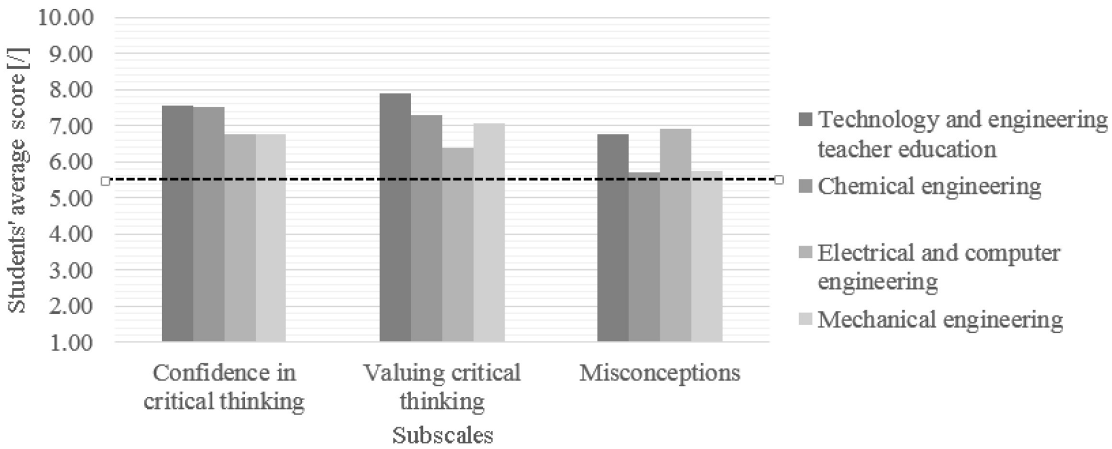

Fig. 2. Students' attitudes and beliefs about critical thinking across the study disciplines with mid-point 5.5.

($F = 15.74$; $df = 1$; $p = 0.000$) with a moderate effect size ($\eta^2 = 0.04$ and 0.06; respectively).

Students' attitudes and beliefs towards critical thinking might differ between study disciplines, as shown in Fig. 2. The test for homogeneity of variance was not significant ($p > 0.05$) for all three subscales of critical thinking. There were significant differences across study disciplines for all three subscales ($p < 0.05$) of *Confidence in critical thinking*, *Valuing critical thinking*, and *Misconceptions* with moderate effect sizes ($\eta^2 = 0.12$, 0.14, and 0.08 respectively). In the case of *Confidence in critical thinking*, a Scheffe post-hoc test revealed significant differences between preservice technology and engineering teachers and electrical and computer science engineering students ($p = 0.00$), preservice technology and engineering teachers and mechanical engineering students ($p = 0.00$), chemical engineering students and electrical and computer science engineering students ($p = 0.00$), and chemical engineering students and mechanical engineering students ($p = 0.00$). Preservice technology and engineering teachers scored highest ($M = 7.56$, $SD = 0.86$) and were followed by chemical engineering students ($M = 7.49$, $SD = 1.09$), Mechanical engineering students ($M = 6.77$, $SD = 1.06$), and electrical and computer science engineering students ($M = 6.75$, $SD = 1.06$).

Valuing critical thinking was most developed in preservice technology and engineering teachers ($M = 7.99$, $SD = 1.07$), followed by chemical engineering students ($M = 7.32$ $SD = 1.40$), mechanical engineering students ($M = 7.07$, $SD = 1.20$), and electrical and computer science engineering students ($M = 6.39$, $SD = 1.69$). A Scheffe post-hoc test revealed significant differences between preservice technology and engineering teachers and electrical and computer science engineering students ($p = 0.00$), chemical engineering students and electrical and computer science engineering students ($p = 0.003$), mechanical engineering students and electrical and computer science engineering students ($p = 0.03$), and preservice technology and engineering teachers and mechanical engineering students ($p = 0.001$). On the subscale of *Misconceptions*, significant differences were found between chemical engineering students and electrical and computer science engineering students ($p = 0.002$) and between mechanical engineering students and electrical and computer science engineering students ($p = 0.001$). The understanding of misconceptions was most developed for chemical engineering students ($M = 5.70$, $SD = 2.05$), followed by mechanical engineering students ($M = 5.75$, $SD = 1.54$), preservice technology and engineering teachers ($M = 6.45$, $SD = 1.74$), and electrical and computer science engineering students ($M = 6.89$, $SD = 1.51$).

4.2 Creative Design Ability of Students

In general, female students ($M = 98.28$, $SD = 22.19$) scored higher than male students ($M = 93.81$, $SD = 28.37$) but there were no statistically significant differences in the total score. The highest score was 161.00 points and the lowest score was 20.00 points. The highest score was achieved by a female student. A between-participant test revealed significant differences in all four categories of creative design ability: *Fluency*, *Flexibility*, *Originality*, and *Usefulness*. The students' average scores across subscales are given in Table 2.

In the case of the *Fluency* subscale, there was a significant difference between female and male students ($t = 4.15$; $p = 0.00$) with a moderate effect size $\eta^2 = 0.06$. Female students ($M = 34.47$, $SD = 10.10$) scored higher than male students ($M = 29.10$, $SD = 11.05$). Female students ($M = 27.49$, $SD = 7.46$) also achieved better results than male students ($M = 24.34$, $SD = 8.23$) on the *Flexibility* subscale. There were statistically significant differences

Table 2. Students' average score on CEDA across sex.

Sex	Fluency		Flexibility		Originality		Usefulness	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Females	34.47	10.10	27.49	7.46	20.66	6.32	15.66	2.51
Males	29.09	11.05	24.34	8.23	23.57	7.87	16.81	4.36

between female and male students (t = 3.28; p = 0.001) with a moderate effect size $\eta^2 = 0.04$. In the case of the *Originality* subscale, there was a significant difference between female and male students (t = –3.35; p = 0.001) with a moderate effect size η^2 = 0.04. Female students (M = 20.66, SD = 6.32) scored lower than male students (M = 23.57, SD = 7.87). In the case of the *Usefulness* subscale, there was a significant difference between female and male students (t = –2.69; p = 0.01) with a weak effect size η^2 = 0.03. Female students (M = 15.66, SD = 2.51) scored lower than male students (M = 16.19, SD = 4.36).

Analysis of covariance revealed that male students, who had lower scores for self-confidence in critical thinking, achieved higher scores on the originality subscale (F = 4.19, p = 0.04, η^2 = 0.02). Furthermore, female students who valued critical thinking more, achieved better results for *Fluency* (F = 4.19, p = 0.04, η^2 = 0.02) while male students performed better on the *Usefulness* (F = 7.47, p = 0.007, η^2 = 0.03) subscale.

Table 3 shows that in general, the highest number of points were scored on average by mechanical engineering students (M = 105.50, SD = 23.92), followed by preservice technology an engineering teachers (M = 96.44, SD = 17.28), chemical engineering students (M = 92.85, SD = 22.86), and electrical and computer science engineering students (M = 86.17, SD = 31.46).

A comparison of different study disciplines reveals that there were statistically significant differences in three categories of creative design ability: *Fluency*, *Originality*, and *Usefulness*. In the case of the *Fluency* subgroup, a Scheffe post-hoc test found differences between preservice technology and engineering teachers and electrical and computer science engineering students (p = 0.02). The preservice technology and engineering teachers (M = 34.19, SD = 10.01) scored higher than the electrical and computer science engineering students (M = 28.88, SD = 12.17), mechanical engineering students (M = 32.67, SD = 26.94), and chemical engineering students (M = 32.92, SD = 10.69). A Games–Howell post hoc test revealed differences on the *Originality* subscale between preservice technology and engineering teachers and electrical and computer science engineers (p = 0.02), preservice technology and engineering teachers and mechanical engineering students (p = 0.00), chemical engineering students and mechanical engineering students (p = 0.00), and mechanical engineering students and electrical and computer science engineering students (p = 0.00). Mechanical engineering students scored highest (M = 26.79, SD = 6.32) and were followed by electrical and computer science engineering students (M = 20.77, SD = 6.94), preservice technology and engineering teachers (M = 20.28, SD = 2.89), and chemical engineering students (M = 18.15, SD = 5.61). In the case of the *Usefulness* subscale, there were statistically significant differences between mechanical engineering students and preservice technology and engineering teachers (p = 0.00), mechanical engineering students and chemical engineering students (p = 0.00), mechanical engineering students and electrical and computer science engineering students (p = 0.00), and preservice technology and engineering teachers and electrical and computer science engineering students (p = 0.02). Mechanical engineering students scored highest (M = 19.09, SD = 2.72) and were followed by preservice technology and engineering teachers (M = 15.42, SD = 1.47), chemical engineering students (M = 15.24, SD = 2.59), and electrical and computer science engineering students (M = 13.77, SD = 4.09). Additionally, analysis of covar-

Table 3. Students' average score on CEDA across study disciplines

Study discipline	Fluency		Flexibility		Originality		Usefulness	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Technology and engineering teacher education	34.19	10.01	26.54	6.44	20.28	2.89	15.42	1.47
Chemical engineering	32.92	10.69	26.54	8.22	18.15	5.61	15.24	2.59
Electrical and computer engineering	27.88	12.17	23.75	9.65	20.77	6.94	13.77	4.09
Mechanical engineering	32.67	9.92	26.94	7.27	26.79	8.03	19.09	2.72

iance revealed that mechanical engineering students, who had a better developed understanding of misconceptions, scored higher on the creativity subscale of *Usefulness* ($F = 4.07$, $p = 0.04$, $\eta^2 = 0.02$).

4.3 Correlations Between Students' attitudes and Beliefs Towards Critical Thinking and Students' Creative Design Ability

Correlations between students' attitudes and beliefs towards critical thinking and students' creative design ability were verified through multiple regression. A multiple regression analysis was carried out with the subscales of students' attitudes and beliefs towards critical thinking as independent variables and creative design ability subscales as dependent variables. We assumed a linear relation between independent (predictor) and dependent (criterion) variables, meaning that we would expect that increases in one variable are related to increases or decreases in another variable. Only regression coefficients (β–weights) with a significance of $p < 0.05$ were considered. A summary of multiple regression analyses is presented in Fig. 3.

Two categories of critical thinking are statistically significant in predicting *Fluency*; i.e., *Valuing critical thinking* ($\beta = 0.19$; $t = 2.77$; $p = 0.06$) and *Misconceptions* ($\beta = –0.13$; $t = –2.10$; $p = 0.04$). Students who better understood misconceptions and better appreciated the importance of critical thinking scored higher on the *Fluency* subscale. Furthermore, students who were aware of the importance of critical thinking scored higher on *Flexibility* ($\beta = 0.17$; $t = 2.49$; $p = 0.02$). *Confidence in critical thinking* predicts *Originality* ($\beta = –0.16$; $t = –2.40$; $p = 0.02$). Students who were more confident in their critical thinking scored lower on *Originality*. The two categories of students' attitudes and beliefs towards critical thinking predicted *Usefulness*; i.e., *Valuing critical thinking* ($\beta = 0.15$; $t = 2.22$; $p = 0.03$) and *Misconceptions* ($\beta = –0.23$; $t = –3.72$; $p = 0.00$). Students who valued the importance of critical thinking and who better understood errors and misconceptions in particular contexts scored higher on the *Usefulness* subscale.

5. Discussion

The present study yielded interesting findings. In general, we obtained evidence that the inclusion of methods, forms, strategies, and cognitive approaches from different disciplines in which there is design activity can provide added value to engineering design in terms of coping with problems and opportunities that we face in real-world settings.

The *Critical Thinking Toolkit* measures students' attitudes and beliefs about critical thinking and was developed for psychology undergraduate students. Stupple et al. [27] proposed exploring the validity of using the instrument in other disciplines. The sample used in the present paper covers different higher-education study disciplines (preservice technology and engineering teachers, chemical engineering students, electrical and computer science engineering students, and mechanical engineering students,) in which design thinking is a core activity

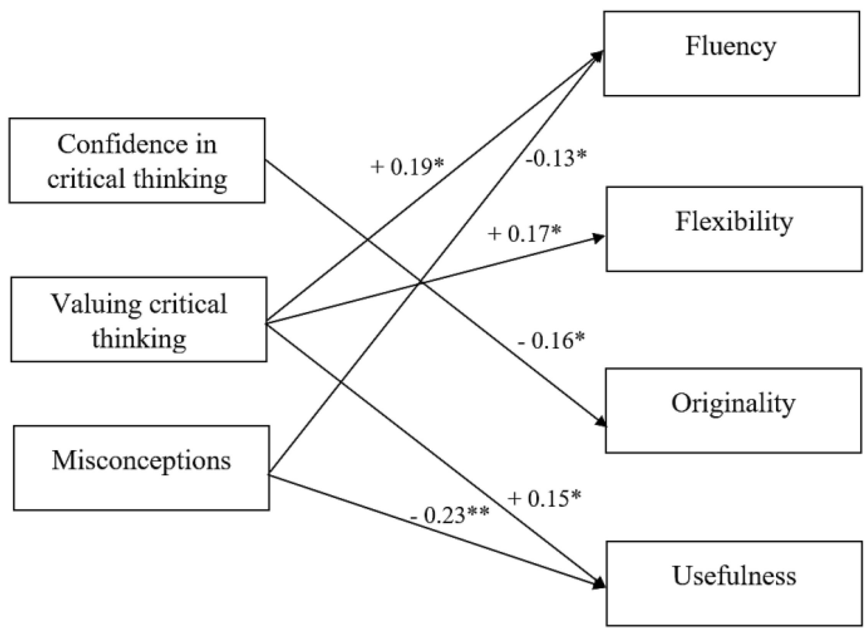

Fig. 3. Students' attitude and beliefs towards critical thinking regressed on creative design ability. Path coefficients are statistically significant at $*p < 0.05$, $**p < 0.001$.

and critical thinking is an important higher-order thinking skill. This demonstrated the reliability of the instrument in other disciplines.

In general, the undergraduate students in the present study had an above-average perceived attitude towards the importance and valuing of critical thinking while their understanding of errors and misconceptions in learning still needed improvement. Furthermore, the students perceived critical thinking as an important skill needed for learning and acquiring competencies. We confirm that critical thinking plays a central role in learning and that it is of utmost importance of higher education. Developing critical thinkers can enhance innovation learning at future employment [27]. We found differences among students in terms of their attitudes and beliefs towards critical thinking that may be due to the different ways that they were taught. The results show that there were statistically significant differences between female students and male students on two subscales of critical thinking: *Confidence in critical thinking* and *Valuing critical thinking*. It turned out that the female students have developed greater confidence in critical thinking and awareness of the importance of critical thinking. In the case of the third factor *Misconceptions*, which measures the understanding of misconceptions related to conceptual learning, students majoring in different subjects had different understandings of misconceptions. These differences were also revealed in a previous study [3]. We further investigated differences in students' attitudes and beliefs among different study disciplines. We found differences among higher-education study disciplines for all three subscales of critical thinking. All study disciplines have critical thinking as an important skill but in different ways. Our results reveal that the preservice technology and engineering teachers had the most confidence in their critical thinking and were followed by chemical engineering students, mechanical engineering students, and electrical and computer science engineering students. Cargas et al. [11] agreed that teachers appeared to be more confident in their mastery of critical thinking skills. Preservice technology and engineering teachers also perceived critical thinking as one of the most important skills that an individual must have. The teachers were followed by chemical engineering students, mechanical engineering students, and electrical and computer science students. Chemical engineering students better understood misconceptions in learning and were followed by mechanical engineering students, preservice technology and engineering teachers, and electrical and computer science engineering students. Chemical engineering students spend much time experimenting and doing other laboratory work and a minimal error or wrong understanding can lead to disaster. To avoid these consequences, the chemical engineering curriculum pays much attention to the understanding of misconceptions. The situation is similar for mechanical engineering, where constructions and systems must be reliable and durable and errors and misconceptions are an important part of the curriculum.

Instructors play an important role in developing critical thinking because they can adapt the learning by encouraging more critical thinking activities. Problem-based learning environment using authentic problems, including critical dialogue and discussion is recommended in the course and mentoring [11]. Online discussions have been suggested as an effective method of improving analytical and problem-solving-skills and critical thinking [30]. Developed critical thinking also contributes to higher academic achievements [27].

In the present study, female students scored higher in the creative design ability test than male students. We cannot conclude that female students are better than male students because previous studies have found that females are better in divergent thinking than males and vice versa [31]. Female students obtained statistically better results in *Flexibility* and *Fluency* while male students scored higher for *Originality* and *Usefulness*. The results show that female students are better at divergent thinking, suggesting that female students perform better in the first phase of the design thinking process, which is to empathize. Female students are more flexible in meeting the needs of users and realizing what is necessary for customers. Furthermore, there were statistically significant differences among study disciplines in the three subcategories of creative design ability: *Fluency*, *Originality*, and *Usefulness*. On the *Fluency* subscale, a higher score was obtained by preservice technology and engineering teachers, while mechanical engineering students performed best on *Originality* and *Usefulness*. Preservice technology and engineering teachers perhaps feel more confident posing different ideas from different knowledge domains because they have gained PCK [3]. Creativity plays a central role in engineering problem solving, but engineers are principally educated to solve well-defined, convergent, analytical problems. Design as a core activity of engineering intersects with several other disciplines where learning outcomes can be showed in different ways. The key to enhancing engineering design might be divergent thinking [2]; i.e., the ability to generate many different ideas and different types of ideas. Design can include the analysis process, which requires divergent thinking, and synthesis, which requires divergent thinking. Divergent thinking can be promoted through various techniques and mind tools used in an interdisciplinary manner, such as brainstorming, heuristics, the SCAMPER technique, the TRIZ method, the six-hats method, and reverse engineering techniques, and the results of the present study thus support the findings of previous studies [3, 14].

There was correlation between students' attitudes and beliefs towards critical thinking and students' creative design ability. Students who better understand misconceptions and better appreciate the importance of critical thinking scored higher on the *Fluency* subscale. Furthermore, students who were aware of the importance of critical thinking scored higher on *Flexibility*. Surprisingly, students who were more confident in their critical thinking scored lower on *Originality*. Students who perceived critical thinking higher perhaps placed more attention on the design process itself, with all limitations and constraints, leading to a rationality of design as argued by [8, 13]. Students who valued the importance of critical thinking and had a better understanding of conceptual misconceptions had better results on the *Usefulness* subscale. Critical thinking and creativity are inextricably linked and together allow effective learning and skill acquisition [32].

6. Conclusions

The present study contributes to the research field by revealing an importance of the interplay between critical thinking and design thinking in an interdisciplinary perspective. The present work will benefit educators and engineering curriculum designers through the optimisation of technology and engineering education from basic to higher education.

Educators should be aware of their students' perceptions of and critical thinking experiences which vary across the study disciplines due to different methods and strategies of teaching critical thinking. Students who have pedagogical content knowledge perceived and experienced critical thinking as very useful higher order thinking skill to cope with real-life problems, while engineering students still rely on algorithmic thinking. Students' understanding of misconceptions is rather interrelated with the method they have been taught the content knowledge.

Students in different academic disciplines practised and perceived design thinking in different ways. Thus, they have diverse design thinking ability to empathise, to create, to visualise, to collaborate, and to make adaptable solutions. Students with a pedagogical content knowledge seem to easier make a transfer of ideas across different contexts, while engineering students rather design several embodiments and prototyping and testing the new product in order to optimise their solutions. Mechanical engineering students outperformed their counterparts especially in user-centric empathy, followed by problem definition or opportunity determination.

In our study, all three subscales of students' critical thinking contribute to their creative design ability. Students who perceived higher values of critical thinking scored higher on the fluency and flexibility of ideas, and the usefulness of their designed embodiments is higher. Furthermore, students' understanding of misconceptions was found as a strong predictor of the usefulness of their designs and of the fluency of their design ideas. On the contrary, students' trust in critical thinking was found as negative predictor of the originality of their designs.

To provide deeper insights and making stronger claims in our work, we need to include additional disciplines in our analysis. In future work, we plan to survey a larger sample of students, including those in fine arts and architecture, and conduct an interdisciplinary quasi-experiment of design thinking activity.

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