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CREATIVE PROBLEM-SOLVING ASSESSMENT AND PRODUCT DESIGN EDUCATION

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ABSTRACT
This study reports findings from the administration of Creative Engineering Design Assessment (CEDA) to product design. The aim is to assess the applicability of CEDA in this discipline for the analysis of students' level of creative problem-solving (CPS) abilities throughout the years of product design education. CEDA measures CPS in four dimensions; i.e., originality, usefulness, flexibility and fluency. 225 students studying at three universities from Istanbul, Turkey completed CEDA on a voluntary basis. The analysis of the data indicates statistically significant differences between 3rd and 4th (on originality), 1st and 3rd (on usefulness), 2nd and 4th (on originality and usefulness), and 1st and 4th (on all dimensions) year students' CEDA scores. Originality aspect of creativity seems to develop more as the students get into their final year, whereas the usefulness develops starting from the second year. While CEDA was useful as a tool to discuss our studio pedagogies, our experience in applying it in the context of product design illustrates the need to revise the instrument according to the nature of this discipline.

Keywords: Creative problem-solving, product design education, millennials, CEDA

1 INTRODUCTION

Creativity is a complex phenomenon that has been theorised by many researchers for many years. Yet, there is no consensus on the definition of this multi-faceted phenomenon [1]. Some definitions focus on personality as the determinant factor of creativity, some on internal and external contexts, and some others on the process of creativity. Among these diverse approaches to creativity, process facet emerged as the overlapping theme for defining creativity [2] [3].

Product design far surpassed the dichotomy of form and function. Expert designers are "ill-behaved" problem solvers [4]. They have to come up with novel, integrated answers to multi-faceted, multidisciplinary problems [5]. This overlaps with the definition of creativity that focuses on the process and gives product design a unique position for the study of creative problem-solving (CPS). This is also one of the reasons why the education of product designers has been structured to include strategies to address creativity. However, we do not know if these strategies are equally affective on millennials who are known for their differences in thinking patterns and acquisition and processing of knowledge.

In order to analyse this phenomenon, we designed a study with two objectives. First, we aimed to investigate the impact of product design education on CPS aptitudes of the undergraduate students; "is there a change in students' level of CPS abilities throughout the years of product design education?" In order to evaluate students' abilities, we borrowed a pretested creativity assessment tool from engineering design, the Creative Engineering Design Assessment (CEDA) [6]. The main reason to adopt CEDA for our assessment is that CEDA offers systematic procedures for applying and evaluating creativity. Moreover, to our best knowledge, there is no study that tests CEDA in the context of product design. This situation defines our second objective. We wanted to test the applicability of CEDA in product design.

2 CREATIVE PROBLEM-SOLVING AND PRODUCT DESIGN EDUCATION

The increased expectation from designers to develop creative solutions also has implications for product design education. The education of "designerly ways of knowing" [7] has always included creativity as a discourse. This discourse involves CPS together with its methodologies and process. Design process involves a blend of rational, analytic and creative modes of thinking [8]. Within this blend, creativity is evaluated as the strength of designers in comparison to engineers and other professionals [9]. This strength gives the designers the ability to develop novel and valuable solutions, in which the value being judged in relation to utility and usefulness [10].

Within the undergraduate design programmes, educators have applied various methods to enhance student creativity. Some of these strategies include the application of analogies [11], design thinking [12] and design research methods [13] within the education. While these strategies provide insights for addressing creativity in product design education, they do not necessarily focus on creativity in relation to millennials. However, millennials are known to differentiate from their peers on certain characteristics. Some of the characteristics associated with millennials are networking, interactivity, multitasking, immediacy, and accessibility [14]. These characteristics define this generation different in their thinking patterns, acquisition, and processing of knowledge. Consequently, the most effective ways of educating millennials have been an ongoing research in higher education [14] [15]. Educating millennials also provide challenges for product design educators. The assessment of the existing studio pedagogies on the enhancement of product design students' ability of creative problem-solving is one of these challenges.

3 ASSESSING CREATIVE PROBLEM-SOLVING WITH CEDA

The perception of creativity is believed to be different in each discipline [6] [16]. Therefore, it is important to apply a creativity assessment tool that best fits a field's nature. Even though, there are insightful tools applied within the context of product design (e.g., [10] [17]), they were designed for different purposes; and therefore, have limitations for assessing CPS abilities of design students studying across different years. In our search for creativity assessment tools in other design disciplines and we came across with Creative Engineering Design Assessment (CEDA) [6]. CEDA is a pretested instrument designed to assess creativity of engineering design students [18] [19]. The instrument has three steps in which students are asked to develop designs to given problems by using sets of three-dimensional figures. In each step, students are expected to sketch 1) two designs, 2) provide descriptions for the designs, 3) offer materials, 4) name additional problems solved by their proposal, and 5) define their users. While developing solutions, students can use one or more of the 3D figures and manipulate the figures in any manner, including size, material, transparency, etc. Subtractions and additions are also welcome. The only restriction is the multiple usages of the given figures. Participants are expected to complete the test in 10 minutes per problem, 30 minutes for total.

We adapted CEDA for several reasons but most importantly it differs from other creativity assessment instruments by focusing on several aspects of CPS simultaneously. These are divergent thinking, convergent thinking, constraint satisfaction, problem finding, and problem-solving. Moreover, it is based on an empirical method that evaluates creativity, which is difficult to quantify [19] and collects data from sketches, which is an indispensable tool for designers. Since it offers quantifiable data, it is suitable for working larger samples and gave us the chance to reach all level students from three universities. CEDA also offers an advantage when the duration of the test time and the millennials short concentration time are considered. Furthermore, Charyton [6] encourages other design disciplines to apply CEDA. However, we didn't encounter any studies that cover product design discipline. As a result, we thought CEDA could serve as a tool to assess creativity in product design.

In the assessment of the sheets, judges are asked to evaluate four criteria of the answers provided: *fluency* (the total number of the designs, descriptions, materials, additional problems and users provided to the problems), *flexibility* (categories, types, or classifications of the responses), *originality* (novelty, new or unique idea), *usefulness* (the practicality of the design, number of purposes and occasions involving present and future uses) [6]. While the scoring of fluency and flexibility are quite objective, the assessment of originality and usefulness have subjective aspects. This is not surprising as creativity involves value judgment [20]. In spite of the subjective character, CEDA scores were found reliable in previous studies [6]. While CEDA promises to address divergent thinking, convergent thinking, constraint satisfaction, problem finding, and problem solving, it is not explained how these aspects of creative process relate to fluency, flexibility, originality and usefulness as measured by the instrument. Thus, it is not clear how to correlate student's scores with the different aspects of creative process.

4 ADMINISTRATION OF CEDA

In order to assess students' CPS abilities, we administered CEDA based on the instructions provided by Charyton [6]. The data was collected from all four levels of undergraduate product design students studying at three universities in Istanbul, Turkey. We collected data from more than one university for two reasons. First of all, our main aim with this study is the advancement of our pedagogic approaches. CEDA helps us find a common ground to discuss the teaching and learning processes taking place in our studios, which are otherwise isolated and disconnected from each other. Second, we wanted to minimise the possible impact of institutional differences on CEDA results.

The selection of the three universities was based on convenience sampling. Each author administered CEDA in her own university. The test was administered on the first day of the studio courses of the 2017-2018 academic year, spring semester. Students participated in the study on voluntary basis. We targeted at least 50% participation from each level. The test sheets were distributed in English. Verbal Turkish explanations were provided whenever needed.

As we aimed understanding the development of creativity throughout the product design education, we combined the data from all three universities and did not look into cross-case variations in the analysis. Each author scored the instruments that she administrated. All the scores were entered to an Excel sheet for the calculation of descriptive statistics. Fluency, flexibility, originality, and usefulness scores of students studying at different levels were compared using one-way ANOVA and Tukey post hoc test. Quantitative results were supported with qualitative analysis.

5 FINDINGS

225 students participated in the study from three universities. 32% of these students were enrolled to first year design studio, 29% to second year, 20% to third year, and 19% to fourth year. Participation of students decreased in number in higher levels since the registered student number to these grades decreased respectively. However, we have achieved 71% participation amongst students registered on all design studio courses.

In total, we expected 675 answers from 225 students (as the test includes 3 questions) that participated to the study. However, 21% of the questions were either unanswered or disqualified. 69 (10% of the total answers) answer boxes were left unanswered in the tests. We think that these participants were not able to finish all three problems on time. The number of unanswered questions is the largest among the first year students and this number drops down as the grade of the students increases (13%, 11%, 7%, and 6% in respect order). In the product design education, we give students several design projects with deadlines in studio courses in each semester. Thus, students practice meeting project schedules and get used to arranging their design process accordingly. This might be the reason for the lower number of unanswered questions in higher grades. In addition to unanswered questions, some students' answers were not solving the assigned design problem, suiting the CEDA rules, or providing realistic solutions. These (11% of the total) answers were disqualified. The number of disqualified answers decrease till the 3rd grade and increase again on the 4th grade (18%, 10%, 2%, 8.5% respectively). It is believed that some of these disqualifications are due to language barrier. For example, some students misunderstood the problem that asks for "designs that can travel" and proposed artifacts that people can carry (e.g., travel pouch) while they are travelling.

Since one of our research questions is dedicated to the change in students' level of creativity throughout the years of product design education, we can conclude our findings as presented in Table 1. When the consecutive education levels are compared, there are no statistically significant changes from 1st to 2nd and from 2nd to 3rd year. Only the originality score increased between 3rd and 4th year students (P: 0.014). When we compare the scores of 1st and 3rd year students, we observe a meaningful increase only in the usefulness score (P: 0.010). Between 2nd and 4th grades, both the usefulness (P: 0.000) and originality (P: 0.000) scores show statistically significant differences. From 1st to 4th year, students' scores are statistically different on all measured aspects of the creativity (Fluency P: 0.001, Flexibility P: 0.001, Usefulness P: 0.000, Originality P: 0.000). Thus, it can be said that since their knowledge on design expands throughout their education, the nature of students' answers expands too.

Table 1. Tukey post hoc test results

	Fluency			Flexibility			Usefulness			Originality		
	Contrast	[95% Conf. Interval]		Contrast	[95% Conf. Interval]		Contrast	[95% Conf. Interval]		Contrast	[95% Conf. Interval]	
1 vs 2	2.385248	-2.043566	6.814061	2.148367	-1.674046	5.97078	0.4122234	-.3655465	1.189993	0.6356164	-.6316852	1.902918
2 vs 3	1.757343	-3.31252	6.827205	1.714336	-2.661353	6.090024	0.6475524	-.2427958	1.537901	0.6772727	-.7734646	2.12801
3 vs 4	3.064482	-2.504361	8.633325	2.536469	-2.269879	7.342818	0.97463	-.0033472	1.952607	1.871564*	.2780442	3.465085
1 vs 3	4.14259	-.8138638	9.099044	3.862702	-.4151062	8.140511	1.059776*	.1893438	1.930208	1.312889	-.1053965	2.731175
2 vs 4	4.821825	-.2830713	9.926721	4.250805	-.1551205	8.656731	1.622182***	.7256817	2.518683	2.548837***	1.088075	4.009599
1 vs 4	7.207072**	2.214789	12.19936	6.399172**	2.090439	10.7079	2.034406***	1.157682	2.91113	3.184454***	1.755915	4.612992

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

These quantitative findings can be interpreted in relation to studied universities programme curriculums. Figure 1 shows us that the usefulness concept of students evolves around 2nd grade. Since usability issues are supported by related lecture courses and design studio courses starting from the 2nd grade in the studied universities, the outcomes seem to be in line with our curricula.

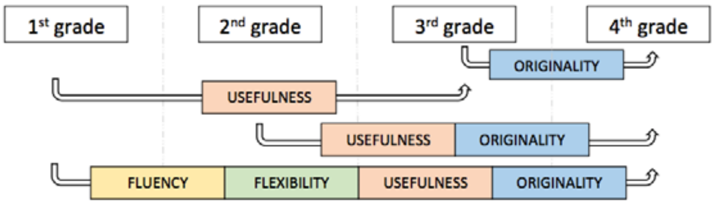

Figure 1. Graphical representation of statistically significant differences

Figure 1 also communicates that the students address originality the most in their final year. At studied universities, user profiles and marketing issues are introduced to the studio courses in the third year. With the introduction of these design factors, students might be realising that usability issues are not enough for designing pleasant products. This might be leading students to look for other factors to develop more original design solutions. This is also evident in their response to two design alternatives for each question. We observed a large number of lower grade students giving very similar answers to their two design alternatives. However, it is also important to note that CEDA is more structured in terms of assessing originality and usability than how these aspects are conceptualised in product design. These creativity aspects might have scored different with the proposed revisions (described in the next section) to CEDA in relation to product design.

Although there is no direct correlation offered by CEDA creators between the aspects of creative problem-solving and assessment criteria (fluency, flexibility, originality and usefulness) of the test, we believe that fluency and flexibility scores of the students are related both with divergent and convergent thinking aspects of the students. Students' fluency and flexibility scores between 1st and 4th year students show statistically significant increase. While scoring the students' answers, we realised that the material, user definition, and additional problems parts of CEDA are the main reasons behind the differences in these aspects of creativity from 1st to 4th year. 1st grade students do not have necessary knowledge on materials, user and additional problems yet. Students advance their knowledge and skills on these topics through the courses starting from 2nd grade. Thus, as the grades of the participants' increase, their solutions improve by means of implement ability, material selection and specific user needs.

6 EXPERIENCE IN APPLYING CEDA TO PRODUCT DESIGN STUDENTS

While CEDA served as a tool for us to discuss how we perceive and assess creativity in product design education, we also made some observations regarding the applicability of CEDA in product design.

"CEDA measures constructs that are a part of the design process as a step by step process, beginning with sketching a design for a problem" [18] and continues with the description of the design, materials used in the design, additional problems solved by that design and finalised with the possible users of the design. Although students are not asked to follow this sequence, the boxes on the answer sheet dedicated to these specific areas somehow guide them to do so. However, in the product design education we encourage students to think and draw simultaneously and to evaluate their thoughts and design on drawings, with drawings, via drawings. This might be the reason why we have had several tests returned with notes on the sketches. Some of these notes include materials, descriptions or additional problems that are addressed by the design. Some others show user-product interaction, the dimensions of the design and/or different usage positions of the design (e.g. closed/opened) (Figure 2).

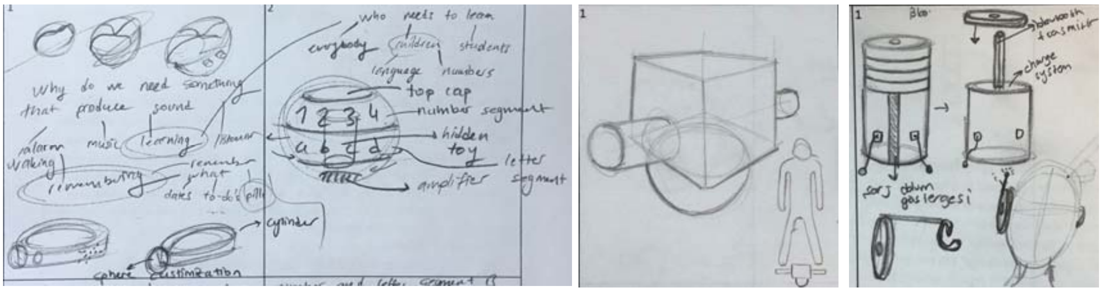

Figure 2. Examples from product design students' answers to CEDA questions

This gives the impression that product design students have a tendency to explain things together with sketches, rather than noting these to assigned boxes. However, as these notes are not written in the boxes dedicated to them, we did not score these notes. In the future, it might be necessary to consider and score the notes on the sketches while applying CEDA to product design students.

Our experience with applying CEDA to product designers showed the product design students tendency to develop abstract solutions. One reason for this might be the given sets of 3D figures. As these are basic geometric volumes, designs were also limited to being very simple in terms of form and, for the majority of cases, unrealistic (e.g. time travelling machine). This situation affected the usefulness of the proposed design solutions and therefore the scores.

Majority of the product design problems include form giving in the process of developing pleasant experiences for users. This form giving activity is also a part of the creativity problem-solving in product design. For this reason, for the context of product design, the originality section of CEDA can be divided into two subsections: the originality of the idea and the originality of the form. This situation is also supported by the CEDA tests filled by students. There were some solutions that involve unique ways of integrating forms with no insightful product ideas or vice versa. Another issue related to form giving is resulting from the expectation to propose design solutions based on assigned basic geometric volumes. These shapes (together with the time constraint) resulted in the development of additive forms. We hardly observed design proposals including integrative or integral forms. This might be interpreted as a limitation of CEDA and as one of the reasons for the development of generic and unrealistic solutions by students. There were occasions were students listed context of use (e.g. movie theatre, concert hall) for the answer to the "users." This can be interpreted as product design students' tendency to cognitively connect context and user. Thus, it might be necessary to score them as well.

7 IMPLICATIONS FOR PRODUCT DESIGN EDUCATION

In this study, we aimed to understand the effects of product design education on millennials via investigating the impact of this education on creative problem-solving aptitudes of the undergraduate students throughout the four years of education. We expect the outcomes of this assessment to improve our pedagogical approach.

The criteria of CEDA that target to assess the knowledge and capabilities on sketch, problem definition, material, additional problems, user needs, time management and alternative creation give valuable insight on students' advancement on these areas throughout their education. Based on the findings from CEDA, students seem to enhance their knowledge on material, user and problem definition, and better manage their time. These are in line with the goals of product design education. Yet, the outcomes of this assessment also revealed some major problematic issues. Not answered and disqualified answers are one fifth of the total responses. Moreover, participants mostly responded to the problems with one design or similar answers, which are an important outcome of this test, since divergent thinking is one of the essential elements of creative problem-solving activity. Although this might be a result of time limitation, we, as tutors of these millennials have the insight that they do not push themselves to propose alternatives, rather they find their one and only solution sufficient. Students are constantly encouraged to create alternative solutions to design problems in the studio courses. Yet, this particular condition is one of the biggest challenges of the authors in design education. We all try to improve our pedagogical approach in order to increase the capabilities of students by means of divergent thinking approach.

Another remarkable outcome of the assessment appears in the usefulness and originality scores. We observed that usefulness development of the students seems to be in line with the aims of product design education. However, there are gaps in the development of originality capabilities of students. We believe some part of this finding might be related to the CEDA's inappropriateness for assessing originality in relation to product design. Another inappropriateness of CEDA was observed in relation to form giving activity with predefined basic geometric volumes. This strategy seems to limit the development of creative forms and therefore solutions of product design students.

As the assessment of creativity is different in each discipline [6] [16] we believe further specifications are needed for the assessment of creativity in relation to product design. It is our recommendation that CEDA should be revised or accompanied with other assessment tools in order to make the assessment to be more specific to product design discipline. Yet, by its systematic, easily understandable and applicable features, CEDA have served well as our first attempt to assess creativity in product design education. We have enriched our knowledge and skills by means of design education and research.

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