The Impact of Multidisciplinary Design Education on the Creative Process in Collaborative Design

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Abstract In an industrial environment, individuals from different kinds of academic backgrounds often form a team to work on a project. This study was designed to find out whether a multidisciplinary design education could have an influence on the process of concept design, which plays a pivotal role in the creative output, in the context of a multidisciplinary team where students from different departments form a team to complete a project. The creativity of the multidisciplinary design teams and of the non-multidisciplinary design teams was compared through a design task conducted twice with heterogeneous participants. Along with our evaluation of the creative output, we classified conversation contents according to a coding scheme in order to find out which design process could have an influence on the creativity of idea sketching. Moreover, we carried out an analysis of the number of conversations and of their contents in the teams belonging to each category. It was found that when students from various departments form a team, students who have received a multidisciplinary design education show more creative idea sketching, take part in more conversations using external knowledge and contributing to the problem-solving process, generate more ideas, and conduct more active reviews and summaries than students majoring in design only.The study enabled us to confirm that multidisciplinary design education was meeting its goal of equipping students with abilities to solve diverse problems that can arise within a team made up of members with different kinds of academic back-grounds in an actual industrial field.

Keywords Multidisciplinary design education, Group creativity, Design process

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1. Introduction

On a group level, creativity in design groups is defined as divergent thinking, as reflected in ideational fluency (Brown, Tumeo, Larey, & Paulus, 1998). This definition is equivalent to the definition of group creativity; the only difference is that the given task is designing. Likewise, a designer's creativity is unleashed when creative imagination is spread over given information, new knowledge and experiences, as with artists and scientists engaged in an array of creative jobs (Na and Cho, 2008). Furthermore, we do not distinguish an individual from a group in the definition of design creativity, but may simply state that creativity is the process of making a product that will be accepted as lasting, useful and satisfactory by a group gathered together for a specific purpose (Taylor, 1975). In other words, the definitions of 'design group creativity' and 'group creativity' are not completely distinct; they only differ in their respective performance tasks and components.

The five components that must be included in the theory of creativity are person, problem, process, product, and climate (Taylor, 1975). The creativity of a design group does not simply depend on an individual's creative functions or the sum of the creativities of all members of a group (Rubin, 1984). Rather, it is determined based on the interaction of the composition and characteristics of these components (Woodman, Sawyer, and Griffin, 1993; Shalley and Gilson, 2004). Moreover, design group creativity is more affected by time, other members of the group, place, setting, do-main-specific knowledge, and individual or group strategies, than by an individual's creative poten-tial (Siau, 1995). Taggar (2002) and West et al., (2003) categorized the components of a design group into an individual member's temperament such as cognitive ability, openness to experience, and conscientiousness, and a group process such as involving others, providing feedback, and ef-fective communication, suggesting that a group's creative output is a result of the group's process-es. Group creativity performance can be viewed as the result of interactions between several im-portant components or dimensions of creativity. These various components or elements can be categorized into Input, Process and Output (Cohen and Bailey, 1997; Shalley and Gilson, 2004; Zhang, Tsui, and Wang, 2011). Figure 1 illustrates the relationships between these components.

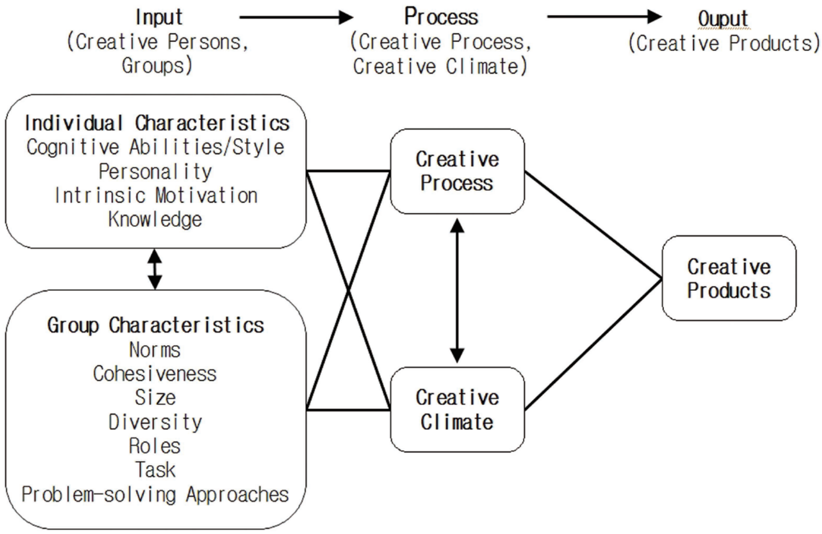

Figure 1 The Relationships among Creativity Components (Siau, 1995)

There are studies that relate creativity and multidisciplinary thinking in design. Jeon (2013) developed a multidisciplinary program that employs design thinking processes to spur multidisciplinary thinking and problem-solving skills in gifted elementary students. Na (2008) stated that the determinative factors in acquiring a creative mind are knowledge and experience, multidisciplinary thinking, creative motives (inner motives), and creative environment (thinking). Jung (2013) explored the differences in an individual's multiple intelligence and types of thought patterns depending on one's multidisciplinary education and design concentration education. The results confirmed that design major multidisciplinary students showed more creative tendencies than non-design major multidisciplinary students, design major non-multidisciplinary students, and non-design major non-multidisciplinary students. Such preceding study results predict that multidisciplinary thinking achieved through multidisciplinary design education will positively affect creativity.

However, thus far, studies on multidisciplinary design education and creativity have been conducted only by way of examining multiple intelligence and types of thought patterns, or of an expert scoring pre-developed multidisciplinary education contents based on evaluation criteria. Such methods fail to examine designers' thinking processes during actual problem solving, and are oriented towards an individual's creativity rather than the team's creativity. Moreover, they also fail to measure problem-solving skills in settings where members from various knowledge backgrounds collaborate (i.e., industrial settings).

The Ministry of Knowledge Economy has set forth the multidisciplinary design school project through which multidisciplinary design education programs have been established. On the 4th year of its progress, this study aims to confirm whether this program is indeed meeting its goals of cultivating design personnel capable of creative and integrated problem-solving that can be applied in the field, through the examination of design task performing processes of students with multidisciplinary design education in a team that comprises members with various concentrations of studies, which resembles that of a real-world industrial field.

2. Design process

2.1. Problem-solving approach

The problem-solving approach represents which factors different teams concentrated on during the process of solving problems while accomplishing a design task. Jin and Kim (2006) categorized various problem-solving approaches. They developed categories that are appropriate for product sketching tasks by referencing the information categories of Suwa and Tversky (1997) Architecture Design task.

Table 1 The information categories

Architecture Design (Suwa&Tversky, 1997)		Design Problem Solving Approach (Jin & Kim, 2006)	
Major Category	Subclasses	Major Category	Subclasses
Emergent Properties	Spaces	Form	Visual Factor, Overall Shape
	Things		
	Shapes, Angles		
	Sizes		Visual Factor, Component Shape
Spatial Relations	Local Relations		
	Global Relations		
Functional Relations	Practical Roles	Function	General Feature
	Abstract features, Reactions		
	Views		Technical Feature
	Lights		
	Circulation of People, Cars	Human	Physical Elements
			Mental Elements
Background Knowledge	–	Context	External Knowledge
		Designer	Intent

<Table 1> (Suwa and Tversky, 1997; Jin and Kim, 2006) illustrates the comparison between the information categories of Suwa and Tversky Architecture Design and the information categories of Jin and Kim Design Problem Solving Approach. Suwa and Tversky subdivided emergent properties, spatial relations and functional relations. On the other hand, Jin and Kim subdivided human elements into physical and mental elements and types of background knowledge into external and internal knowledge, and examined them more closely.

2.2.Group Activity

The group activity represents the processes through which a group approached problem-solving, and it is categorized depending on the design process. In their on-site study of group activity, Olson et al. (1992) made 10 observations of software design problem-solving meetings that took place in the course of a small group project. They categorized design meeting activities into three —Design, Review and Summary, and Coordination— categories, and again divided these categories into 11 sub-categories in their subsequent study, as shown in <Table 2>.

Table 2 Coding scheme for the group activity process

Olson et al.(1992)	Ocker&Fjermestad (2008)
Issue	Design
Alternative	
Criterion	
Clarification	Review and Summary
Summary	
Walkthrough	
Goal	Coordination
Project Management	
Meeting Management	
Digression	Other
Other	

Ocker and Fjermestad (2008) further modified the task used by Olson et al. (1992) and utilized it to analyze the process by which Virtual teams (VT) designed the Computerized Post Office (CPO) by reaching a consensus through collaborative work via computer-mediated on-line communication systems. They sorted group activities into 'Design, Summary, Coordination, and Other' categories depending on the design process, and into 'Debate and Supportive' categories depending on the team climate, and subsequently employed these categories as the basis for analyzing the conversations of business graduate students and for comparing the quality of output (Functionality, Interface layout, Coherence of these ideas) and creativity.

3. Experimental design and methods

3.1.Participants

We conducted a preliminary experiment (1st experiment on November 16, 2011) in order to confirm what multidisciplinary design education seeks to achieve: namely, whether members from various knowledge backgrounds working together indeed influence a group's problem-solving skills. We first divided our participants into two teams, one team with students of the same major (design team), and the other with students of various majors (multidisciplinary design team), and compared the creativity of the two teams based on the variety of the members' study concentrations. Through the actual experiment (2nd experiment on August 12, 2013) with a different participant pool, we aimed to find significant results by dividing students with different knowledge backgrounds into two groups. We gave multidisciplinary design education to one group and only traditional design education to the other group, and compared the task accomplishment processes of each team.

All the participants of this study were students of Sungshin Women's University. Sungshin Women's University has implemented multidisciplinary design education after being selected to participate in the multidisciplinary design school development project. It was selected as the first-year base university for the multidisciplinary design school development project in 2011, along with Seoul National University and KAIST, and was subsequently awarded for its excellent operations, as evidenced by the outstanding performance results of its multidisciplinary design education program.

The 1st experiment participants comprised of 12 junior design majors from the multidisciplinary design education program, 12 junior design majors from the traditional design education program, and 12 sophomores to seniors from other departments, for a total of 36 students. They were grouped into 12 teams of three. Of these 12 teams, 6 teams were heterogeneous with each group consisting of 1 design major and 2 non-design majors, while the remaining 6 teams were homogeneous with each group made up of traditional design majors only, or of participants in the multidisciplinary education program only.

The results of the first experiment showed that the difference in creativity was only present among heterogeneous teams. In order to further examine the creativity of heterogeneous teams, we conducted a second experiment with different participants and divided the teams into a multidisciplinary design major team and a design-only major team. Both teams comprised members of various study concentrations. A total of 36 students participated in the second experiment, including 7 design major juniors and 2 design major seniors from the multidisciplinary design education program, and 2 design major juniors, 7 design major seniors, and 18 non-design major students ranging from freshmen to seniors, all from the traditional design education program.

Table 3 Groups

	Homogeneous team	Heterogeneous team	
	1st Experiment	1st Experiment	2nd Experiment
Design–only	· homogeneous design teams(ODT) : design majors	· heterogeneous design teams(EDT) : design–only major + non–design majors	
Multidisciplinary Design	· homogeneous multidisciplinary design teams (OMT) : multidisciplinary design majors	· heterogeneous multidisciplinary design teams(EMT) : multidisciplinary design major + non–design majors	

In both experiments, each team was composed of 3 members. Cast et al. (2012) stated that a 3-5 member team is the optimal size, suited for stable conflicts of opinions that lead to effective problem solving. A larger team would have longer decision-making processes and would require a competent leader in order to carry out consistent and efficient outcomes. On the other hand, a smaller team would show higher levels of concentration and would be fitted for ideational conflicts that can prevent hastily settling on a single idea.

The multidisciplinary design students in the first and second experiments took multidisciplinary education courses for 2-3 years, with experiences in 2.5-11 month-long corporate projects. In addition to taking an industrial design course, the multidisciplinary students were required to take 'Industry-Academia Team-Teaching Capstone Design 1,2' courses. We varied the two heterogeneous groups by enrolling one group in the multidisciplinary design education program and the other group in the traditional design education program. Besides this variation, however, we ensured that all the participants had similar GPAs, and non-design major members of both groups were selectively chosen so that both group members had similar majors and a similar proportion of freshmen to seniors. Furthermore, to ensure similar levels of interest in design among non-design major students, we only drew our participants from students taking design courses as electives that had voluntarily signed up to participate in a design experiment.

3.2.Experiment Procedure

We sought to examine the difference between the creativity of the output produced by a team of design and non-design major students who had received multidisciplinary design education and a team with similar design and non-design major students who had only received traditional design education. We also sought to examine their design processes. The procedure was as follows.

The creativity produced by a team during the brainstorming stages is different from that produced during the in-depth discussion stages (Gong, Suteu, and Shen, 2009; Bechtoldt, De Dreu, Nijstad, and Choi, 2010). We therefore divided the design process into the brainstorming stage and the in-depth discussion stage. The time allotted to perform the design task was divided into experiment A and experiment B. Experiment A (brainstorming) required sketching or writing the description of the ideas produced in the group, without limitations and consideration of implementation methods. Experiment B (in-depth discussions) required choosing an idea from the prior session (Experiment A) or a new idea and further developing it based on a specific method for its realization and then writing and submitting its design background, design concept, and design solution image.

In the 1st experiment, each team was allotted a time limit for each task (Experiment A: 20 minutes, Experiment B: 50 minutes). In the 2nd experiment, each team was allotted a total of 70 minutes for both tasks so that we could examine how both the heterogeneous multidisciplinary team and heterogeneous design team distributed their time between brainstorming and idea development. This was on the basis of other studies that had found that creative teams allocate less time to the brainstorming process. Ocker and Fjermestad (2008) divided participants into a high-performance team and a low-performance team based on the measurements of creativity and the quality of their outcomes. The analysis of communication among team members showed that high-performing teams spent less time on brainstorming and rather carried out more detailed and rigorous discussions. In addition, Cho and Jung (2006) found that after the initial collection of ideas, the longer participants invest in executing their idea and the more active their discussion, the greater the originality of their output. Thus the study showed that although the initial concept is indeed important, the originality of the output is strongly dependent on the creativity of the discussion and idea realization process.

Each team was given 10 sheets of B4 size paper, pencils, erasers, and one computer. The entire process of the experiment was filmed with two cameras for each team. Each team was given a computer for research, with a 10-minute and 15-minute limit in experiments A and B respectively. The time cap was lifted in the 2nd experiment.

3.3.Design Task

The topics given in the design task were as follows: ‘It is 7 PM in the evening. How can we make people feel better after work?’ (1st experiment) and ‘How can we make a family’s weekend outdoor activities more enjoyable?’ (2nd experiment).For our present study examining design creativity, we selected a task that could reveal integrated problem-solving ability. The task was also one on which a design major had little impact and which was easily accessible to non-design majors in everyday life. The design task for creativity evaluation needs to be challenging, realistic, appropriate for the subjects, not too large, feasible in the time available and within the sphere of knowledge of the researchers, as well as centered around a problem that is typical as far as industrial design practice is concerned in that it calls for the integration of a variety of aspects (Dorst and Cross, 2001). Moreover, La (2012) stated that the more conceptual the topic of a project is, the more important it is for a team to have members from various study concentrations. Thus our choice of topic, which was quite conceptual, was appropriate for the task of team design.

3.4.Measurements of Individual Creativity

In order to verify whether an individual's creativity affected group creativity, individual creativity tests were given. The participants each performed three actions: receiving one TTCT Figure A test sheet and following the test giver's instructions, completing the figure and attaching the name during the given time.

The results of the individual creativity test showed that the average creativity of the multidisciplinary team students and design team students were 53.1 and 56.4 respectively, and the average creativity of the design major students with multidisciplinary design education and design major students with traditional design education were 55.8 and 53.8 respectively. However, because the significance of probability (p-value) for the homogeneous groups in the 1st experiment was 0.725 and that for the heterogeneous groups in the 1st and 2nd experiment was 0.456, the difference of aver-age creativity among members of the multidisciplinary team and of the design team was statistically insignificant. Likewise, there was no significant difference in individual creativity among the design major students with multidisciplinary design education and those without. In other words, it was confirmed that there was no significant difference in creativity among individual team members in the multidisciplinary team and in the design team, and the same was true for the design major students with multidisciplinary design education and those without.

Table 4 Individual Creativity

	Homogeneous Team			Heterogeneous Team		
	Design	Multidisci-plinary Design	P-value	Design	Multidisci-plinary Design	P-value
Team	(N=9) 59.22	(N=9) 61.57	0.725	(N=27) 56.36	(N=27) 53.06	0.456
Design Majors	(N=9) 59.22	(N=9) 61.57	0.725	(N=10) 53.8	(N=10) 55.8	0.661

4. Experiment Results and Analysis

4.1.Assessment of the creativity of group idea sketching

Design output creativity was judged by three experts based on prepared evaluation sheets. The judges consisted of two professors and a doctoral candidate in design. The evaluation sheets were drawn up according to the Korean creative product evaluation tool (Kim and Lee, 2004; Lee, Kim, and Choi, 2007) developed by modifying Besemer's (1999) Creative Product Analysis Model (CPAM) and Creative Product Semantic Scale (CPSS) to reflect the cultural peculiarities of Korea for the purpose of assessing the degree of product creativity.

According to CPAM, the evaluation dimension comprises of 3 factors: Novelty, Resolution, and Elaboration and Synthesis (Style) (Besemer, 1998). Novelty represents the newness of materials, process, concept, and methods to produce output; Resolution represents a product's usefulness or the extent to which it solves a problem; Elaboration and Synthesis (sometimes called "Style") contains stylistic elements of the output (Besemer and O'Quin, 1999; Kim and Lee, 2004).

The Korean creative product evaluation tool was developed through methods that involved exploring synonyms and performing content analysis on words that depict the properties of "creative output". The final evaluation tool differed from the original three-component structure. Among the nine sub-components of the original structure, the organic component under the elaboration dimension was excluded and only eight sub-components were included in the final tool. Moreover, this evaluation tool was confirmed to be effective on evaluations of outcomes in different areas and in Korea.

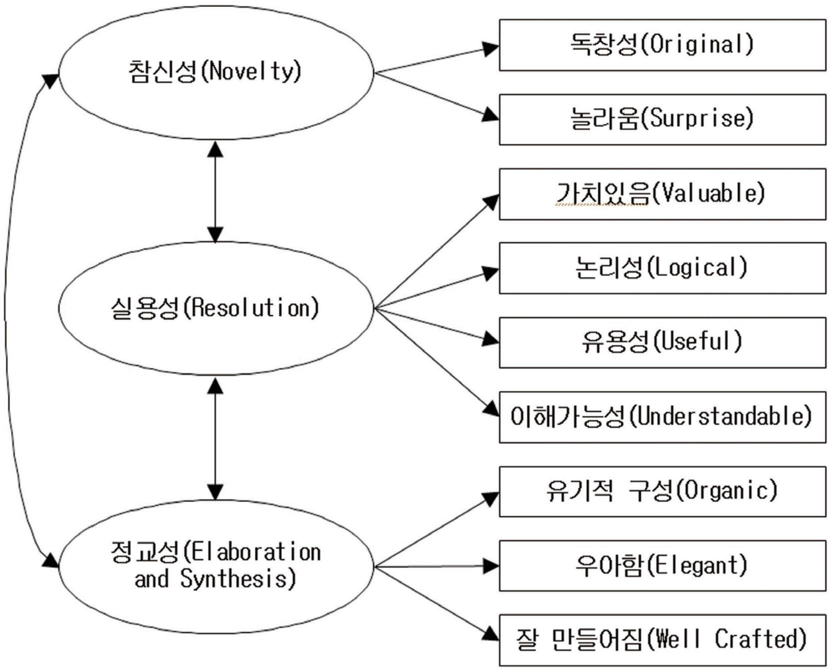

Figure 2 Creative Product Analysis Metrix(Besemer, 1998)

In this study, the evaluation tool is structured with three components and eight sub-components - novelty (surprising, original), resolution (logical, useful, valuable), style/elaboration and synthesis (organic, well-crafted, elegant). The responses to these questions were evaluated on a 7-point scale and the average of the three components was taken as the 'creativity' measure. Separately from this, a single 'score' question was established to assess the overall creativity of the design. It asked, "On a scale of 100, how many points would you give to this design?"

Table 5 The inter-rater reliability of the output of 1st experiment(N=36)

	Novelty	Resolution	Elaboration & Synthesis	Average
Experiment A	0.767	0.722	0.696	0.892
Experiment B	0.844	0.897	0.864	0.815

Table 6 The inter-rater reliability of the output of 2nd experiment(N=36)

	Novelty	Resolution	Elaboration & Synthesis	Average
Experiment A	0.761	0.634	0.607	0.738
Experiment B	0.890	0.632	0.660	0.703

The output evaluation results showed the Chronbach's coefficient value, which signifies the degree of congruity among the 3 judges, to be 0.6 or higher for all evaluation items of the 1st and 2nd experiment, indicating high measurement reliability.

In the 1st experiment, for the homogeneous groups that consisted of students with the same majors, there was no significant difference in the creativity scores and ratings of design output between the students who received multidisciplinary design education and those who did not. Hence in order to examine the effect of multidisciplinary design education, we conducted a 2nd experiment targeting the heterogeneous groups that had shown a difference in creativity.

Table 7 Thecreativity evaluation of 1st experiment (homogeneous groups)

	Experiment A			Experiment B		
	ODT(N=9)	OMT(N=9)	P-value	ODT(N=9)	OMT(N=9)	P-value
Novelty	3.84	3.87	0.477	3.86	4.69	0.057
Resolution	4.40	4.77	0.272	4.66	4.26	0.237
Elaboration & Synthesis	3.88	4.22	0.231	4.49	5.39	0.010
Average	4.04	4.28	0.301	4.34	4.76	0.137
Score	58.89	61.11	0.385	62.22	65.00	0.362

Table 8 The creativity evaluation of 1st experiment (heterogeneous groups)

	Experiment A			Experiment B		
	EDT(N=9)	EMT(N=9)	P-value	EDT(N=9)	EMT(N=9)	P-value
Novelty	3.39	3.46	0.459	2.86	3.34	0.096
Resolution	3.39	3.46	0.452	3.59	5.32	0.000
Elaboration & Synthesis	3.71	3.26	0.112	4.22	4.14	0.385
Average	3.80	3.69	0.408	3.54	4.27	0.005
Score	53.00	51.11	0.426	44.33	61.11	0.015

Table 9 The creativity evaluation of 2nd experiment (heterogeneous groups)

	Experiment A			Experiment B		
	EDT(N=18)	EMT(N=18)	P-value	EDT(N=18)	EMT(N=18)	P-value
Novelty	3.25	3.47	0.331	2.76	4.63	0.000
Resolution	4.10	4.03	0.419	4.33	4.81	0.050
Elaboration & Synthesis	3.31	3.03	0.186	4.58	4.15	0.092
Average	3.56	3.51	0.443	3.88	4.52	0.024
Score	45.8	52.6	0.113	47	63.7	0.002

We conducted the 2nd experiment with a different participant pool and tasks from the 1st experiment. There was no significant difference in creativity between the heterogeneous multidisciplinary team (EMT) and the heterogeneous design team (EDT) during the brainstorming task (experiment A), but a difference in creativity was found during the in-depth discussion (experiment B). This further strengthened our results that revealed a significant difference in creativity during the idea development processes between the heterogeneous multidisciplinary team (EMT) and the heterogeneous design team (EDT).

Table 10 The creativity evaluation of 1st and 2nd experiment (heterogeneous groups)

	Experiment A			Experiment B		
	EDT(N=27)	EMT(N=27)	P-value	EDT(N=27)	EMT(N=27)	P-value
Novelty	3.34	3.57	0.266	2.79	4.24	0.000
Resolution	4.21	4.15	0.403	4.08	4.96	0.001
Elaboration & Synthesis	3.30	3.09	0.162	4.45	4.15	0.095
Average	3.61	3.60	0.488	3.77	4.45	0.002
Score	47.56	53.06	0.127	47.3	63.3	0.000

We therefore examined the reason for these differences shown between the design-only teams and multidisciplinary teams in the heterogeneous groups of experiment B (in-depth discussion) by performing a transcript analysis of the creative process. To do so, we transcribed the recorded conversations of the participants and then performed an in-depth analysis by using Nvivo9, a tool for qualitative study of the problem-solving approach and group activity process.

4.2Group process creativity analysis

4.2.1. Coding scheme for problem-solving approach

In order to examine which components the participants placed an interest in in approaching the problem to complete the design task, we divided their communication according to the categories presented in <Table 11>. This classification is on the basis of 'information category classification' presented by the case study on the explorative protocol analysis of user design activity by Jin and Kim (2006).

Table 11 Coding scheme for problem-solving approach

Code		Examples in this study experiment
Form Visual Factor	Overall Shape	■ We should draw both situations and resting at home…and also draw things like forests… ■ So we don't have to do three-dimensional stuff. I think we have three people, so that's better than doing it one-dimension.
	Component Shape	■ So I'm thinking of something round in the center and that can beam in a 360 rotation… ■ Do the functions of this lens have to be so two-dimensional?
Function	General Feature	■ Like a system that delivers the money straight to me? So I don't have to pick it up myself? ■ Music plays as soon as the switch turns on. And pleasant voices of my family play from the answering machine… When I hear the voice.
	Technical Feature	■ We can use cell phones, through applications ■ You are talking about things like ubiquitous that's hot on commercials right now, right? The one that turns on with a button?? Do we just have to develop on that?
Human	Physical Elements	■ Using all five senses? I mean there are different ways to use all five senses, like use your hand to feel something or taste or smell things. ■ But soft is convenient. Though it is not good for eye health.
	Mental Elements	■ That sort of thing. A sense of belonging? Something like that. Activities that can instill a sense of belonging to mom, dad, and siblings, even while doing outdoor activities. ■ A kind of feeling that ensures I have done my part? A sense of self-satisfaction such as "I am a responsible head of my house who works hard and also goes on family trips on the weekends"? I think what we need here is a self-satisfaction rather than something for everyone.
Context _ External Knowledge		■ I mean they worked hard to make money. So something like I don't have to work for money anymore… ■ The problem for people these days is that they don't have time to go out on the weekends.
Designer Intent		■ It should be easy to see. They said during class that they can just see it ■ Well, Apple called it Siri, so we should name it… Should we name our logo?

4.2.2.Problem-solving approach-related conversation analysis

The 'Number' category of <Table 12> displays the categories that showed differences in the number of the EMT's and EDT's conversations related to each category. Significant differences were found in two areas: the EDT had more conversations employing designer internal knowledge than the EMT, while the EMT had more conversations related to the overall shape, general feature, technical feature and context. The EDT only had more conversations than the EMT in the 'designer intent' category, and the p-value also confirmed that this category had the most significant difference.

Table 12 The conversations relate to the problem-solving approach between the EDT and EMT

		Number			Proportion		
		EDT(N=27)	EMT(N=27)	P-value	EDT(N=27)	EMT(N=27)	P-value
Form Visual Factor	Overall Shape	43	99	0.020	0.08	0.12	0.112
	Component Shape	105	146	0.097	0.20	0.18	0.461
Function	General Feature	91	208	0.003	0.18	0.26	0.217
	Technical Feature	29	69	0.020	0.06	0.09	0.180
Human	Physical Elements	10	41	0.035	0.02	0.05	0.068
	Mental Elements	33	59	0.056	0.06	0.07	0.344
Context_External Knowledge		58	109	0.013	0.11	0.14	0.462
Designer Intent		149	69	0.009	0.29	0.09	0.004

'Proportion' represents the proportion of a specific category-related conversation to the number of total conversation related to the problem-solving approach. It shows each team's most favored category in the problem-solving approach.

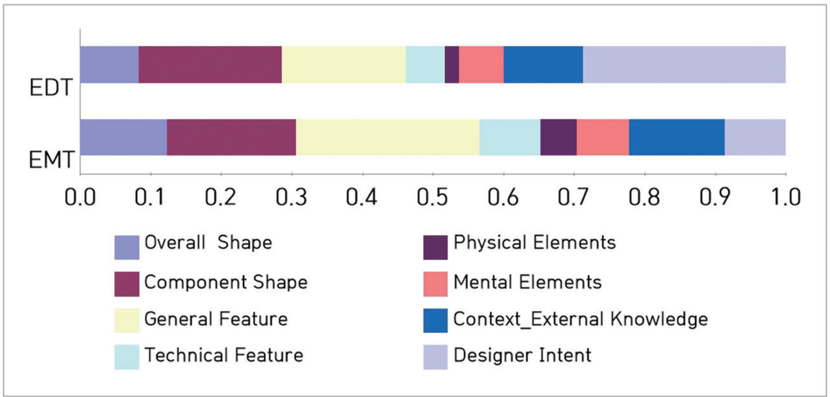

Figure 3 The conversations relate to the problem-solving approach between the EDT and EMT

The following shows an example of a conversation between the EDT members. Not only the design major students, but also the non-design major students of the EDT put more emphasis on the judgments of designers. The EDT members met one another for the first time at the beginning of the experiment, and only had a short period of time to get to know one another, but nevertheless, they built an intimate and active vibe that allowed them to make jokes while presenting designer intents and also grant them the opportunity to freely introduce counter arguments or negative feedbacks.

design2: I think we can develop on the idea #6, and..... I like this the best.....
non-design major: We can't realize that idea.
design2: Yes. It's unfeasible.
non-design major: We can, but our environment is completely....
design2: Yes. Rain... That's too bad.....

design1: It kind of feels like service design.

The following shows an example of a conversation between the EMT members. The EMT mem-bers mostly discussed context-related topics, considering ideas such as the role of each family member, the spatial environment in which they live, and the structure of a modern family. They al-so focused their discussions on the functions that should be included in families' outdoor activity games. The multidisciplinary students were mostly engaged in context-related conversations. The non-design major students were equally involved in conversations, but all of their discussions were regarding general functions, and they usually spoke in shorter sentences than the multidisciplinary students.

multidisciplinary 1: The background is.. wait. What if we write it out in order? Why outdoor activities? Why don't they like kids? What's so uncomfortable?
multidisciplinary 2: The topic was why must we do outdoor activities. Why outdoor activities.
non-design major: Because it gives families their own secluded family space.
multidisciplinary 2: Why outdoor activities? Because at home, they have their own roles.
non-design major: Their own spaces.
multidisciplinary 1: They lack communication because of the space. Communication structure. Through outdoor activities, in a new environment.
multidisciplinary 2: Before. New environment and new space, this basically means the same thing. They expect that they would be able to communicate better in a new environment. It's kind of like a change of atmosphere would make things better. This is somewhat related to the experiential facet.
non-design major: A new experience.
multidisciplinary 1: And um. let's write it like this. What. What is so inconvenient in outdoor activities. And, having too many things to carry is inconvenient, and in terms of products, I think it's kind of a drawback, having to increase the luggage load. And. Should we organize it here?
multidisciplinary 2: We somewhat have a plus. They remember better. I have a lot to say. I'm the youngest one, so I have much to say about older brothers.

4.2.3.Group activity analysis coding scheme

We examined each group's procedures throughout the idea sketch by analyzing their conversations related to the group activity. We thus divided the process into categories of 'issue, alternative, and criterion.' Also, since in this study there is already a given topic for the task, the 'issue' was further divided into 'task' and 'new topic.' The 'task' is the communication that takes into account the elements '7 PM in the evening,' 'after work,' 'make feel better,' 'family' and 'weekend' included in the topic; 'new topic' is a new problem that needs to be considered in the design task outside the topic given in the task.

Table 13 The group activity process

Olson et al.(1992)	Ocker and Fjermestad (2008)	This Study	
Issue	Design	Issue	Given Task
			New Topic
Alternative		Alternative	
Criterion		Criterion	
Clarification	Review and Summary	Review and Summary	
Summary			
Walkthrough			
Goal	Coordination	Coordination	
Project Management			
Meeting Management			
Digression	Other	Other	
Other			

Table 14 Coding scheme for group activity process

Code		Examples in this study experiment
Issue	Given Task	■ We're supposed to make people that returned home at 7 PM feel better. The time is 7 PM because they work and that is when people come home from work ■ It is not about what the outdoor activity is. It is about how we can make outdoor activities more enjoyable.
	New Topic	■ Then this time let's consider two aspects. Psychological? Or physical? Let's focus on these two kinds of pleasure… ■ Making them happy and giving them pleasure can be… We can listen to their life worries, or we can just try to reduce their emotional burdens. Which do you think is better?
Alternative		■ Pressing a button will send invitations to your close friends. ■ You know how there are fliers at the doorways? We can use that idea and put funny stories or jokes instead of fliers.
Criterion		■ But isn't this the best idea for giving pleasure? Overall? Hmm…..I mean, I think so, personally. ■ But don't you think this is too flat? Too bland?
Review and Summary		■ So what you mean by making people who come home from work feel better… should be something that makes food taste better or make it smell better… That sort of thing, right? ■ I thought about that. You know, the ideas we have come up with so far are only situations when someone's alone.
Management		■ Well, let's start writing things on the first page and then go on ■ Are we supposed to do this until 5:05? Are we not done yet?
Other		■ I am hungry. Do you have class? ■ My hands are chapped from the crafts class.

The heterogeneous design team and the heterogeneous multidisciplinary team showed a significant difference in two categories: the 'Alternative' category, where students propose new ideas, and the 'Review and Summary' category, where the students review and organize the previously proposed ideas. In both of these categories, the multidisciplinary group had a significantlygreater number of conversations – especially in the 'Alternative' category, with twice as many conversations as in the heterogeneous design team.

A comparison of both teams' group activity-related conversations showed that the heterogeneous multidisciplinary team had focused more on generating new ideas than the design team, thus leading to a significant difference in the 'Alternative' category. Next runner-up was the 'Other' category, which implies that the heterogeneous design team focused more on conversations not pertaining to the design task.

Table 15 The conversations relate to the group activity between the EDT and EMT

		Number			Proportion		
		EDT(N=27)	EMT(N=27)	P-value	EDT(N=27)	EMT(N=27)	P-value
Issue	Given Task	17	11	0.125	0.02	0.01	0.117
	New Topic	18	17	0.229	0.02	0.01	0.226
Alternative		227	473	0.001	0.22	0.31	0.005
Criterion		88	118	0.068	0.08	0.08	0.419
Review & Summary		449	658	0.011	0.43	0.43	0.405
Management		144	185	0.089	0.14	0.12	0.214
Other		100	55	0.096	0.10	0.04	0.098

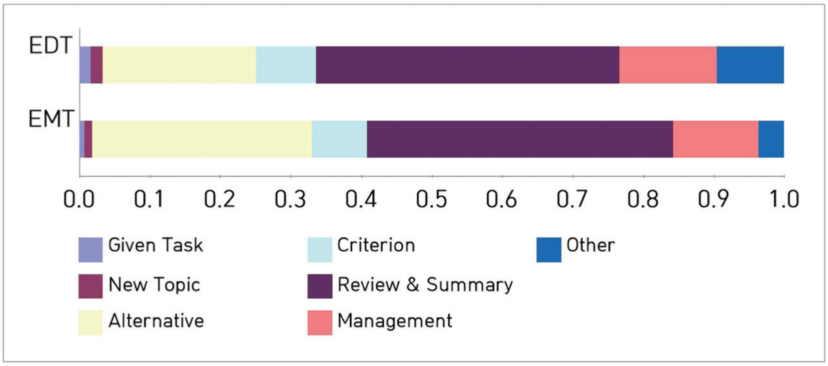

Figure 4 The conversations relate to the group activity between the EDT and EMT

The following is an example of a conversation among the heterogeneous design team that illustrates the traits of their group activity. This heterogeneous design team shows an even distribution of design activity, even in a short period of time, that encompasses considerations of topic-pertinent aspects and the given task, new idea generation, criticism, review, and time management. Furthermore, despite the fact that all three members of the team were meeting one another for the first time, the two design major students mainly carry on the conversation with each other, leaving out the non-design major student from the conversation most of the time. In addition, although the conversation was irrelevant to developing their ideas, the two design major students created an intimate climate by complimenting each other's opinions and offering business partnerships.

> design 1: We could not come across these all too easily in the neighborhood. Also it's kind of boring going to the same places all the time.
> design 2: Hmm. Families should engage in outdoor activities more. It seems to be cooling down, but why do we do this? Explain. Why? What did we say the reason was? Did we say it is difficult to find a proper outdoor activity? Easily?
> design 1: Changing the place that we always go to? A new and unique place so we can make more memories.
> design 2: Do you think we can offer something unique? A unique place. To make new memories. Offer new memories. Oh, we had one more, right? The... what is it, not only for our family, but also for others who can gather through the use of the application....
> non-design major: A community.
> design 2: Communication. Hmm. Yeah. How can we make this more family-oriented?
> design 1: With more people, in a broader scope.
> design 2: By mixing and mingling, we can instill a sense of family love, develop family relationships and social relationships. Communication, let's do this. Community. Getting the contents. This is really good. Do you want to build on this later?
> design 1: Business.
> design 2: Seriously.
> design 1: This is really original.
> design 2: It is, really. So we came up with it like this

The following is an example of a conversation of the heterogeneous multidisciplinary team, which shows the traits of their group activity. Unlike the earlier heterogeneous design team that showed various design activities, the heterogeneous multidisciplinary team focused on generating ideas and organizing previously proposed opinions. When proposing new ideas, they recapped previous discussions and elaborated on their own opinions with great detail. Moreover, their conversation was balanced among all three members— two non-design major students and one multidisciplinary student.

> non-design major 1: Here is camping. Camping, or swimming, and we have to control the time, should we lay it out in a natural way, or should we make people ask for it? Oh, would they fight? This is just like that. The time here, the time in this building and the time outside the building is different. In the morning, I want to go camping, then I can go right away, like it is night here, but it is day outside.
> multidisciplinary: So that is more like morning and night, than the actual time. I went at night, but it's set to daytime. Then we should play

it out like this. There are two stages for each place, night and day.
non-design major 1: Yes, that sounds okay. But, this has to feel real. The fresh and cool breezes in the mountains and things like bugs have to be realistic. Although it is indoors, there should be trees, and exposed tree roots.
multidisciplinary: So bugs… have to be real…..
non-design major 2: Alive.
multidisciplinary: But putting real bugs there is.. a bit… we should not, right?
non-design major 1: Maybe like bug feed.
non-design major 2: We have to get rid of that because we have to make a pleasant environment. Just make the sounds real.
non-design major 1: Yes, I agree, there should be no bugs. Indoors, sound of bugs, but not real bugs. Then do we plant real trees?
multidisciplinary: I think we should, but then it would be hard for the trees to grow, right?

5. Conclusion and discussion

This study aimed to examine the effects multidisciplinary design education has on design creativity by observing the processes through which various groups accomplish design tasks, and analyzing the produced results. We examined each group's task performance process in the conceptual design stages. The conceptual design process is related to idea generation (Ulrich and Eppinger, 2004) because it is a decisive design process when all the factors that influence the realization period of a design are found and important decisions are made (Ullman, 2010). This study also sought to confirm whether multidisciplinary design education is indeed fulfilling its goal of training talented students with competent problem-solving abilities to effectively address numerous problems that can arise during conceptual design phases in actual industrial fields where team members' study concentrations are diverse and varied. For this purpose, we divided design processes into the problem-solving approach and the group activity categories and various sub-categories according to design idea sketching outputs and schemes. Furthermore, we performed a multifaceted analysis, through which we aimed to propose a creativity evaluation framework for assessing the effectiveness of multidisciplinary design education programs. We also classified different conversations in the design problem-solving process into various scheme categories to find out which properties of creativity in design processes are related to or are fostered by multidisciplinary design education.

An analysis of the conversations during the idea sketching experiment showed that for the heterogeneous teams that had members from various study concentrations, the team that had received multidisciplinary design education demonstrated creative traits during problem-solving processes. The evaluation of this team's idea sketching displayed a higher creativity score than the other team that had only received traditional design education. Such results confirmed that multidisciplinary design education is indeed fulfilling its goal of fostering talented students with competent problem-solving abilities to effectively address numerous problems that can arise in actual industrial fields where teams comprise of members with a variety of knowledge backgrounds. Hence we have confirmed the need for multidisciplinary design education. In addition, an analysis of the conversations during the problem-solving processes further confirmed that students who had received multidisciplinary design education exhibited some traits during the planning process that pertain to the creative traits during the design process.

Based on these results, the conclusions and suggestions of the present study on design education are as follows.

Firstly, the creativity of the EMT was found to be higher than that of the EDT only when the students took enough time to develop one or two ideas, rather than when they had to generate numerous ideas in a short period of time. This relates to the idea that the creativity of the output is determined during the discussions and development of an idea, not in the initial brainstorming stage (Cho and Jung, 2006; Bechtoldt, De Dreu, Nijstad, and Choi, 2010). We therefore suggest that these findings be factored in when shaping design education curricula. Multidisciplinary design-major education should be amended so that students can be trained to foster creativity even when generating various ideas in a short period of time, and traditional design-major education should be modified to encourage students to narrow the scope of their ideas during the brainstorming process so that they can conduct more in-depth discussions to draw out more creative output.

Secondly, in conversations on the problem-solving approach, the EDT placed greater weight on the internal knowledge and judgment of designers, whereas the EMT focused more on outside knowledge, overall shape and function. This matches the findings of Jin and Kim (2006) that the amount of information designers have on the circumstances, external knowledge, and general features positively correlates to the creativity of their produced concepts. The EDT tended to concentrate on particular content, especially giving much weight to designer intent. The EMT considered much more diverse aspects of design content. According to Chakrabarti and Bligh (1996), generating a wide range of concepts is important, so that valuable concepts are not overlooked. If designers can develop promising concepts, this should increase the possibility of creating better products. Hence it can be said that the possibility is higher for the multidisciplinary teams in the heterogeneous groups, who considered design contents from more diverse aspects, to produce better outputs than the design teams. We therefore suggest design education train students to consider a wide array of aspects such as circumstances, external knowledge, and general features, rather than focusing only on the internal knowledge of designers.

Thirdly, analysis of conversations on the group activity process showed that the EMT actively engaged in idea generation and review and summary. The most significant difference from the heterogeneous design team was when proposing new ideas, which was also supported through comparisons of conversation frequencies and conversation focuses. The EMT's top characteristic, that is to say an active review and summary aptitude, was the same as for the high design performing team in Rosalie and Jerry' 2008 study. In the latter study, the members of the high design performing teams summarized the discussions among their team members about the given topic, and structured a way to organize the team's tasks and current progress. On the other hand, members of the low design performing teams rarely summarized their discussions, and when they did, their summaries were merely restatements of what other members had previously said. Hence we suggest education content developers focus the content on encouraging members of a design group to actively engage in debates during problem-solving, rigorously propose new ideas, and to review and summarize proposed ideas.

The significance of this study lies in having empirically verified the effectiveness of multidisciplinary design education through a multifaceted analysis of the groups' design processes and outputs, and having singled out the aspects of creativity during design processes that are linked to multidisciplinary design education. Moreover, these results were strengthened from attaining similar results through two trials of experiments. However, this study has limitations due to the fact that it was conducted on students. We must observe students actually working in the field after graduation in order to verify whether multidisciplinary design education indeed fosters problem-solving capabilities that can be employed in the field. Thus we advise a follow-up study to examine whether students who received multidisciplinary design education show a difference in their creativity in the field, compared to those who received traditional design education.

In addition, in order to confirm whether designers had a boost in creativity through multidisciplinary design education by collaborating with non-design major students, we also had to examine how the control group (homogeneous team) solved its given tasks. By comparing the performances of the team that received multidisciplinary design education with that of the team that received traditional design education, we were able to confirm that there was no significant difference in design output creativity between the groups when not collaborating with other non-design major students, whether they have received multidisciplinary design education or not. However, further research is imperatively needed in order to denote a significant difference between homogeneous groups, as only one trial of experiment was conducted on a limited pool of participants.

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