



Collaborative digital environments to enhance the creativity of designers



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ABSTRACT

This study explores the interaction of the essential components of creativity and collaboration in a digital environment in the design process. The framework is based on Amabile's componential theory of creativity, which is composed of three intra-individual components of creativity and the social environment. The digital environment as the social component of creativity provides the technical infrastructure for the analysis of data related to creativity and collaboration. Protocol coding method is used for the analysis of the qualitative and quantitative data stored in The Modular Object Oriented Developmental Learning Environment (MOODLE) forum posts that were formed by the comments or critiques given during the collaboration process by the team members, instructors or jury members. Findings indicate that the social environment component named as the reactivity to proposals is closely related to idea generation as the creative relevant process component and group interaction as the task motivation component. Furthermore, it is found that the number of sketches and design ideas produced through critiques are the main design issues that enhance creativity in collaborative digital environments.

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1. Introduction

The creativity support environments extend the capability of designers for making creative designs in the conceptual phase of design. According to Greene (2002), the digital environments support creativity in design process at two different levels. At the first level, they support the creativity of designers in knowledge gathering, knowledge sharing and knowledge integration and in idea generation. At the second level, the digital environments should support the design of creative products in a particular domain while providing the essential creativity characteristics. Furthermore, the digital environments should provide support for the integration of these two levels in a creative design process.

In the National Science Foundation Workshop Report, Shneiderman, Fischer, Czerwinski, Resnick, Myers, (2005) stated the goal of a digital environment is to develop improved software and user interfaces that give power to the users for being more productive and innovative. Shneiderman, et al., 2005 added that the improved interfaces search more effectively in the intellectual resources, develop collaboration among even geographically distributed teams and provide rapid design processes. Also, comparing the digital

environments with the traditional ones, Nakakoji (2005:70) concluded that “because creativity is such a humane matter, designing, developing, and evaluating tools for supporting creativity will uncover issues and challenges that have not been so obvious in the traditional HCI [human–computer interaction] research framework”.

Fischer, Rohde, and Wulf (2007) defined the term ‘social creativity’ as working together to solve a problem with the help of the computer media and technologies. The collaboration process is a core concept for social creativity in design problems that requires expertise in a wide range of domains. Solving design problems requires “different perspectives, exploit conceptual collisions between concepts and ideas coming from different disciplines, manage large amounts of information potentially relevant to a design task, and understand the design decisions” (Fischer, Giaccardi, Eden, Sugimoto, & Ye, 2007; Fischer, Rohde, & Wulf, 2007: 16).

Focusing on the relationship between the problem solving process and digital environment Vandeleur, Ankiewicz, de Swardt, and Gross (2001: 269) named the creative relevant processes as direct creativity indicators and stated that they are “...observable behavior that is a prerequisite for creativity to take place...”. Furthermore, they named the domain-relevant skills and the motivation components as indirect creativity indicators and stated that they are not necessary for creativity to take place, but they enhance creative activities.

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In the literature, some applications and digital environments that support creativity are present, such as the Envisionment and Discovery Collaboratory (EDC), Caretta and I-LAND (Warr & O'Neill, 2007). Warr and O'Neill (2007:128) described the characteristics of these tools as “EDC supports the design process as a group activity; Caretta supports personal and shared spaces throughout the design process; and I-LAND supports individual, sub-group and group activities in design”. EDC as creativity support tool facilitated shared understandings and provided a common ground in design activities through problem framing, idea generation and idea evaluation. Caretta allowed the manipulation of physical and virtual objects in the shared spaces while providing the opportunity to examine the ideas in the personal spaces. Besides, I-LAND has a dynamic nature for the integration of new technologies in three different interaction spaces.

In the last years, the creativity environments focused more deeply on the brainstorming process in order to enhance the group creativity. As, the Idea Expander is a creativity support environment that establishes communication among the members with pictorial stimuli that are based on the brainstorming sessions (Wang, Cosley, & Fussell, 2010). Also, the Interactive Creative Collaborative Environment (ICE) concentrates on the brainstorming sessions while combining the physical space with a digital space where the meeting room is equipped with an interactive table, interactive multi-touch screens and whiteboard walls (Benyon & Mival, 2012). Furthermore, the Idea Playground system supports both synchronous and asynchronous sessions for idea generation based on the brainstorming sessions with a pen based large digital whiteboard, multiple projectors and mobile computing devices (Perteneder et al., 2012).

Design process is composed of a sequence of goal-oriented problem solving activities. The efficiency of the creativity support environments and the amount of information retrieved from the design team members determine the level of creativity and the quality of the design process (Afacan & Demirkan, 2011). Integration of digital collaboration to design process broadens a designer's point of view by enhancing the ability to share and assess various design concepts and ideas. As Csikszentmihalyi (1996) explained the social characteristics of creativity as “does not happen inside people's heads, but in the interaction between a person's thoughts and a sociocultural context. It is systemic rather than an individual phenomenon” (p. 23). In a collaborative digital design medium, designers form teams and members of the team in this social environment share experiences, ideas, resources or responsibilities.

Creative designing is also viewed as a process that develops iteratively in design problem space and solution space (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2004; Wiltchnig, Christensen, & Ball, 2013). Furthermore, collaborative design is considered as an innovative activity when the members of the team have shared understanding on the design process as well as being familiar with the team members (Kleinsmaa & Valkenburg, 2008; Pearce & Ensley, 2004). The quality and amount of communication among the team members is an effective measure in the assessment of success in collaboration (Shen, Ong, & Nee, 2010). However, Hulsheger, Anderson, and Salgado (2009) found that the quality of communication is more effective for creativity and innovation compared to its composition.

The previous research on creativity was either focused on the development of software and digital environments (Nakakoji, 2005; Shneiderman et al., 2005) or on the social creativity elements that foster the creativity of the individuals or organizations in collaboration sessions (Benyon & Mival, 2012; Perteneder et al., 2012; Wang et al., 2010). It is a widely agreed issue that the creativity in design solutions increases, if the team members in a collaborative digital environment develop them from various perspectives (Karakaya, 2011).

Firstly, this study focuses on the intra-individual components that influence creativity in digital environments. Task motivation, domain-relevant skills and creative relevant processes are considered as the three intra-individual components that influence creativity in the social environment (Amabile, 1996).

Secondly, the indicators of collaboration activities and the communication pattern characteristics that determine the social environment component in the design process are identified. This study deeply focuses on the indicators of collaboration that were introduced by Calvani, Fini, Molino, and Ranieri (2010). Furthermore, the communication patterns in the collaborative digital environment are analyzed using the Functional Category System developed by Jonassen and Kwon (2001).

Thirdly, this study tries to find the interactions between the intra-individual components and social environment components. Communication acts among the team members stored as the design critiques reveal the creativity components as well as the collaboration characteristics among the team members. The digital environment as the social component of creativity provides the technical infrastructure for the relevant data. Over the past years, mostly researchers have analyzed either the intra-individual components or the social environment components separately. In this study, building on Amabile's (1996) componential theory of creativity, which is composed of three intra-individual components of creativity and social environment, the design process of collaborative teams in a digital environment is analyzed. Furthermore, this study delves deeper in each component and tries to find the interaction of the two components in a real design environment.

2. Componential theory of creativity

For the past 25 years, research focusing on creativity in design has been influenced by what is known as the 4P's of Rhodes (1961): person, process, product, and press (environment). “Due to the nature of design process, designers solve problems that are not well defined and the methods that they use are not fully understood” (Demirkan & Hasirci, 2009: 294). The 4P's helped designers to structure their thinking on design creativity in solving these not well defined problems. Therefore, the previous research in design, mostly with a disjointed vision of creativity, was based on the independent components of creativity (Demirkan & Afacan, 2012; Demirkan & Hasirci, 2009; Hasirci & Demirkan, 2003). Recent trends in creativity research show that the social environmental forces influence creativity in design. Thus, the present study aims to approach to creativity in design in the social environment building on Amabile's (1996) componential theory of creativity.

According to the componential theory of creativity of Amabile (1983 and 1996), task motivation, domain-relevant skills and creative relevant processes are the three intra-individual components that influence creativity in the social environment. Furthermore, the external component named as the social environment could affect each intra-individual component. As Amabile (1983) stated in the Intrinsic Motivation Principle of Creativity, intrinsic motivation evolves from the individual's perceived value of engaging in the task itself while extrinsic motivation stems from the outside sources. Furthermore, she added that while intrinsic motivators are positively challenging the creative behavior of individuals, the extrinsic ones could weaken creative behavior. Based on the latter evidences found in the researches, Amabile (1993) concluded that extrinsic motivation sometimes act together with intrinsic motivation in supporting creativity. Working in organizational settings, Zhou (2003) found that close monitoring of a supervisor as an extrinsic factor has a negative effect on the intrinsic motivation while developmental feedback has a positive effect on the intrinsic motivation. Furthermore, Liu, Chen, and Yao (2011) found that the

autonomous internalization of an activity while making it as a part of one's identity supports job creativity both at the individual and team level in organizational context.

The componential theory of creativity has been tested and applied in numerous psychological studies since 1983 (Amabile & Pillemer, 2012). Studies concentrating on the team level concluded that specific behavioral measures of the components of creativity were related to standard individual differences (Taggar, 2002). Thus, the members with creative supporting behavior provide a suitable social environment for the creative teams. Hirst, Van Knippenberg, and Zhou (2009) also found that the team creativity could be affected by the individual creativity through team learning. Besides, they stated, the preference of the individuals that develop positively new skills, enhances the team creativity. These studies on teams were mainly conducted in the organizational context.

While prior research in problem solving has primarily considered creativity as a significant issue in design process, limited number of them has examined creativity as it naturally unfolds in real design domains. Christiaans and Venselaar (2005) pointed the difficulties of making creativity research in design process by referring to the analysis on the cognitive processes of designers. Today, there are various computer tools that enhance creativity of design students in collaborative digital environments. More empirical research is needed to understand the dynamics of collaborative digital environments that ultimately lead to the development of creative design solutions.

Based on Amabile's (1996) componential theory of creativity, this study analyzes creativity in the design process in a collaborative digital environment to answer the following questions?

- (1) What are the intra-individual and social environment components of creativity in design process?
- (2) What are the interactions of the intra-individual components with the social environment components?
- (3) How are the sketches and design ideas are related to the creativity components in design process?

The related hypotheses of the study are as follows:

- (1) The interactions among the intra-individual components and social components enhance creativity in a collaborative digital environment.
- (2) Design issues as the number of sketches and design ideas is highly correlated to the social creativity component.

Thus, this study explores the components of creativity and collaboration in a digital design environment in the design process as it naturally unfolds in real design domain through the comments and critiques given by the team members. Moreover, this study deeply explores the intra-individual components and social environment components as well as their interaction. The number of design ideas and the number of sketches produced as the externalization of design ideas are considered as elements that enhance creativity.

3. Method

3.1. Participants

The study was conducted with all the registered senior year students of an undergraduate elective course titled 'Visionary and Future Environments' in the Department of Interior Architecture and Environmental Design at Bilkent University, Ankara, Turkey. The Turkish participants in the study were twenty-seven design students divided into nine teams of three members who were

assigned randomly. The age range was 21–28 (mean age = 22.26, SD = 1.35). Among the participants there were eight males and nineteen females. The students were experienced in designing spaces in a digital environment as the senior year design students. The participants collaborated both on and off campus on the design project.

3.2. Digital environment

The Google SketchUp is the main software that is used in this study. The Google SketchUp drawing database can store data either as a single identity or library components (SketchUp User's Guide, 2006). In addition, it has a connection to the Google 3D Warehouse, which is a collaborative library and it is used in previous studies and proved to be efficient for the collaboration of the team members (Afacan & Demirkan, 2010; Afacan & Demirkan, 2011). The Modular Object Oriented Developmental Learning Environment (MOODLE, <http://www.MOODLE.org>) is used to develop, store and deliver course materials as in text and image formats as well as increasing communication and collaboration facilities (Fig. 1).

The MOODLE forums provided the technical infrastructure for online messaging and uploading/downloading a variety of files such as the text documents, SketchUp 3D models, and image files (Fig. 2). On campus, the team members and design instructors collaborated with each other while giving critiques, generating alternative solutions and deciding on a suitable solution for the design problem. Besides, off campus collaborations among the design team and design instructors occurred after the class hours.

In this research, the creative process is being analyzed by using the MOODLE database and communication records of the design students. The students participated in-group discussions through the MOODLE forums. These discussions involve activities such as giving constructive comments to a design, criticizing other students' designs or participating in the collaborative process. In the literature, the use of online discussion groups has demonstrated that contributions to online discussion are assessable and learners contribute meaningfully to group discussions (Alvesson & Kärreman, 2000; Dennen, 2008; Pektas & Demirkan, 2011; Reushle et al., 1999).

3.3. Procedure

The study was conducted in the 'Visionary and Future Environments' course that has an aim of global perspective and investigation of the means to conceptualize, plan and design visionary and futuristic environments. Therefore, in the given design problem the students have to design a space habitat with the relevant design requirements that are different from a habitat on earth as well as the priorities assigned to these requirements. Recent researches indicated that exploring the challenges of habitation design fosters the creativity of design students (Doule, Saleny, Herin, & Rousek, 2012; Harrison, 2010; Robinson, Sterenborg, Häuplik, & Aguzzi, 2008).

Consequently, the given problem was to design a space hotel for the accommodation of six single space tourists. This space hotel was situated on an orbital station consisting of several modules. It should include a public area and several private areas to meet the following basic needs of space tourists for sleeping, cleaning, eating, exercising and socializing.

The duration of the study is 8 weeks. In the first week of the study, the design students were informed that they would receive the design critiques and would meet in the same virtual learning space and every communication would be documented in the MOODLE forum. Firstly, the MOODLE and the design problem were introduced to the design students. In the following four weeks, the design students were asked to design the space hotel and allocate

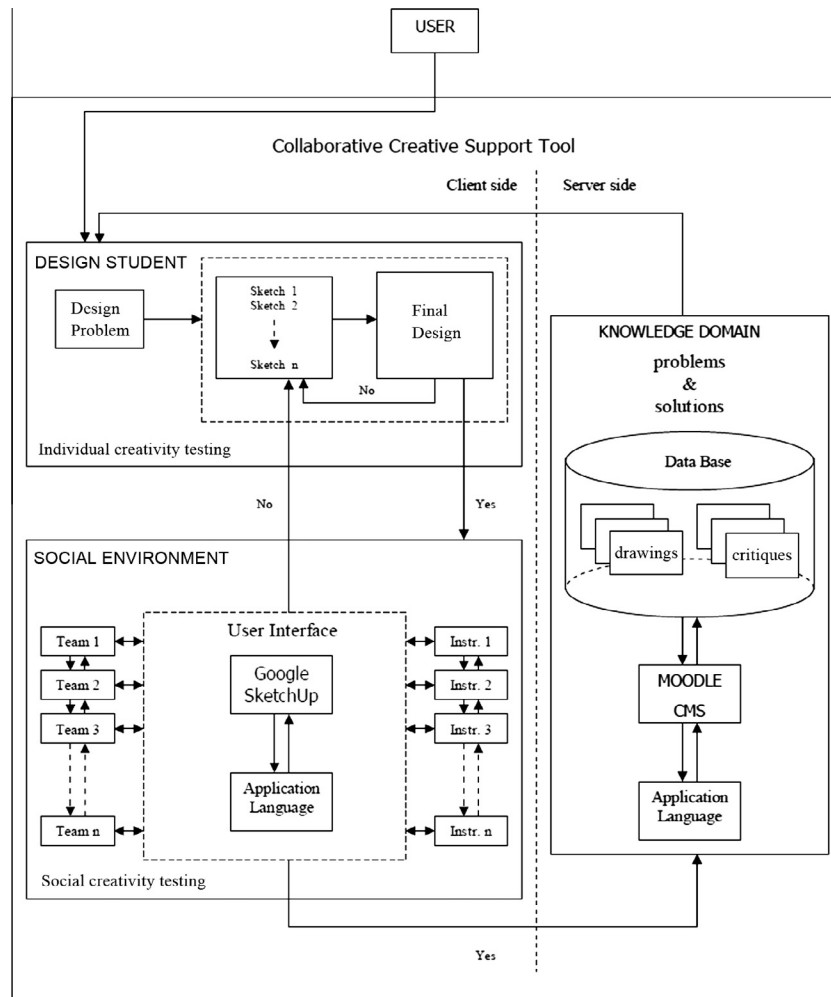


Fig. 1. The digital environment.

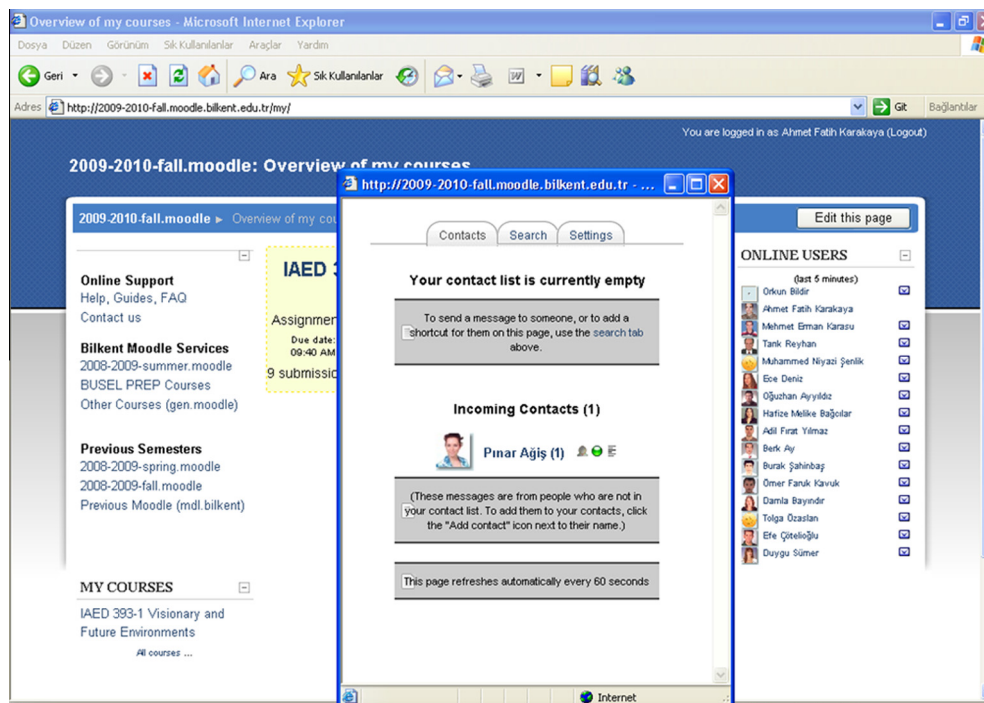


Fig. 2. A screenshot from the MOODLE message window.

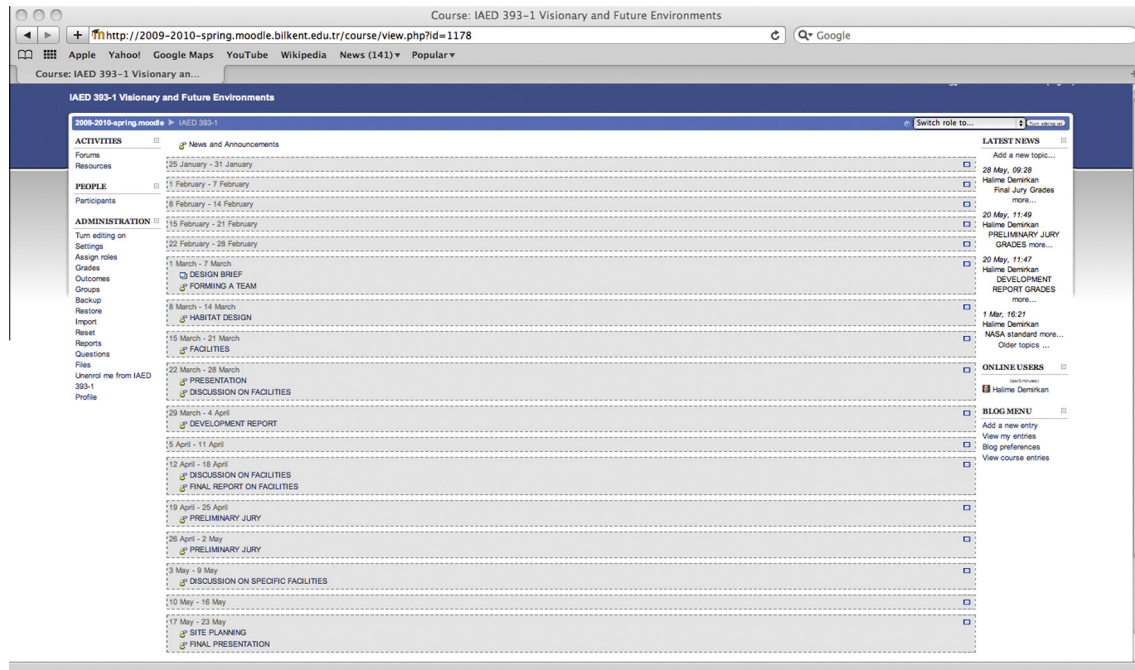


Fig. 3. A screenshot from the MOODLE student interface.

the required spaces by using the 3D modeling tool (Fig. 3). On the fifth week, a preliminary jury with two guest jury members was done. Last week, a final jury was conducted as a final evaluation and discussion. In design education, each design project is reviewed by a jury composed of fellow students, instructors and guest jury members from inside and/or outside the institution. In juries, the team members present their design proposals, then the jury members comment on and discuss the issues that it raises the quality of the design solutions.

The design teams collaborated while developing their design problems in this study. On the first week, each team member was asked to upload individual sketches. The design team members generated a number of ideas about the design problem. Each member uploaded the sketches explaining his/her best view. After individual sketches, each team member criticized the other team members' ideas, made modification comments on the sketches and discussed the alternative solutions. After the social creativity testing process, a final solution was generated and one team member uploaded it to the MOODLE forum (see Fig. 1). These uploaded files could be downloaded and observed by the other design teams and instructors.

3.4. Protocol coding

For evaluating the creative process and analyzing the support given by MOODLE to the design students, the protocol coding method is used (Ericsson & Simon, 1985). The protocol coding was done on the information stored in the MOODLE forum posts. The students were designing the space hotel for the accommodation of six single space tourists on an orbital station. In order not to interfere with the design process, they were collaborating among the team members as a familiar act experienced in the previous design studios. The protocol coding method focuses on the MOODLE forum posts, where the segments are driven from a single comment or critique based on a single issue of the design project. This single issue is stated either in a single sentence or phrase; or in some cases more than one sentence for clarifying a certain de-

sign issue. These segments are the parts of critiques or comments that affect the design student's creative process.

Protocol coding of the intra-individual creativity components and social environment component are based on Amabile's (1996) componential theory of creativity. This theory is applied and tested in numerous psychological studies (Amabile & Pillemer, 2012) and the scope is relevant to the present design study. The *creative relevant processes*, *domain-relevant skills* and *task motivation* are coded as the three intra-individual components of creativity. The external component named as the social environment by Amabile (1996) is the collaboration environment and the collaboration indicators are derived from Calvani et al. (2010). These indicators are grouped in 5 categories; namely, the *extent of participation*, *equal participation*, *extent of roles*, *reactivity to proposals* and *rhythm*. The content of each component, its relevant sub-components and the way it is segmented is described in detail in the following sections and the examples for the related subcomponent segment is given in Tables 1–4 for qualitative data and Table 5 for quantitative data.

The coding of each category was done by the two experts independently; thus the possibility of affecting each other while assessing the segments were eliminated. The analyses are grouped under creativity codes, communication patterns and indicators of creativity. The internal validities are controlled by Alpha Cronbach tests: only the ones over 0.8 were taken into consideration. Firstly, *pre-knowledge* category in the domain relevant skills component was consisted of three subcomponents (knowledge, skills and experience) and these subcomponents had internal validities below 0.8 and these were combined and assessed as one category since it was hard to differentiate the subcomponents for the experts.

3.4.1. Protocol coding of intra-individual creativity components

Building on Amabile's (1996) componential theory of creativity, which is composed of *creative relevant processes*, *domain-relevant skills* and *task motivation* as the three intra-individual components of creativity, the MOODLE forum posts are segmented. These segments are analyzed and frequency of posts in each component was identified.

Table 1

Examples for the creative relevant processes components.

Creative relevant processes	Team	Subject	Example
Generating ideas	T7	S19	Space tourists may see the earth from the resting modules
	T7	S20	We can cover all the modules with a transparent material
	T7	S19	Also we can rotate modules around central module to see different angles
Experimenting	T5	S14	The eating area should not be usual
	T5	S15	How the space tourists eat something without gravity?
Persistence	T3	S8	We should use cylindrical shape for connection module
	T3	S7	If we use cylinder, we cannot create a G force, we should still use a torus

Table 2

Examples for the domain-relevant skills component.

Domain-relevant skills	Team	Subject	Example
Pre-knowledge	T8	S22	We should design plumbing
	T8	S21	Without a gravity force, water behaves differently

Table 3

Examples for the task motivation component.

Task motivation	Team	Subject	Example
Group interaction	T2	S4	Could you add some light into the activity module?
	T2	S6	Ok, I'll modify it
Motivation	T1	S2	I've added the new design.
	T1	S3	It's very functional, looks great :)

Table 4

Examples for the Functional Category System of design process (adapted from Jonassen & Kwon, 2001).

Phases	Team	Subject	Example
PA	T2	S5	We should use special structures in theatre stage for flying and disappearing
PC	T1	S3	Shell thickness is important, how much it should be?
OO	T7	S19	We should use pyramids to enlarge shell
CD	T5	S14	Social space module should have waste evacuation
SD	T8	S23	We could install cameras into a thick shell
SA	T4	S11	Great idea
SC	T7	S20	To use pyramids is good idea but has to consider friction
NT	T1	S3	I was alone in my room yesterday, it was difficult

The creative relevant processes component is analyzed under *generating ideas*, *experimenting* and *persistence* categories. The domain-relevant skills component is analyzed under *pre-knowledge* category. This component involves the knowledge, skills and experience that creative people call from their memory. As Vandeleur et al. (2001) stated they are interwoven and their internal validities were below 0.8 in this study. Therefore, they are considered as one group. Task motivation component is analyzed under *motivation* and *group interaction* categories. These two categories are based on Amabile's (1983) Intrinsic Motivation Principle of Creativity as she named them as the intrinsic and extrinsic motivation. Later, many researchers concentrated on task motivation mostly in organizational settings (Amabile, 1993; Liu et al., 2011; Zhou, 2003).

The ability of an individual to produce ideas is an important human characteristic that can be expressed as a verbal proposition or

Table 5

Design team activities throughout the study.

Design teams	No. of posts	No. of sessions	No. of synch. sessions	No. of ideas	No. of sketches
T1	124	17	7	15	12
T2	94	9	3	9	7
T3	16	4	3	3	4
T4	24	19	10	26	31
T5	38	8	4	13	9
T6	15	11	2	21	27
T7	76	10	7	13	24
T8	56	22	13	21	17
T9	19	4	2	6	4
Total	462	104	51	127	135

in a drawing (Carroll, 1993). *Generation of new ideas* is an important aspect of creativity, since students may not be able to find a suitable solution for the given problem in the first sketch. Generating number of ideas help students to come up with a solution after developing many ideas. *Experimenting* is another aspect of creativity that occurs when students try different solutions for a design problem. Carroll (1993) named this act as 'figural fluency' and described it as the success in producing a variety of drawings for a specified task. Another creative relevant process category is the *persistence*. If students carry on their idea to develop it for a better solution, persistence occurs. *Persistence* category involves a cyclic procedure between idea generation and experimentation. The following segmentation examples show the *generating ideas* and *experimenting* categories of the creative relevant process component (Table 1). *Persistence* occurs if the segments are alternating between the *generating ideas* and *experimenting* segment/s in a collaboration session.

The domain-relevant skills component consists of the *pre-knowledge* category. When design students use their previous knowledge, experience and skills to create something, it is called *pre-knowledge* category of creativity. The following are examples of the *pre-knowledge* category of the domain relevant skills component (Table 2).

In this study, the task motivation component consists of the *motivation* and *group interaction* categories. Group interaction occurs when students criticize the sketch of the team members to trigger more ideas. Giving critiques to each other in a team helps in developing a solution to the design problem (Sagun & Demirkan, 2009). Motivation is a driving force to achieve goals in design process. The following examples show the *group interaction*, and *motivation* categories of the task motivation component (Table 3).

3.4.2. Protocol coding of the social environment component (the collaborative environment)

Building on Amabile's (1996) componential theory of creativity, the external component named as social environment is the digital environment where the collaboration among the team members occurs. The criteria for evaluating the social environment compo-

nent, the collaboration indicators are derived from Calvani et al. (2010). Indicators of collaboration are grouped in 5 categories; namely, the *extent of participation*, *equal participation*, *extent of roles*, *reactivity to proposals* and *rhythm*. To evaluate the collaboration indicator categories of the design teams, the MOODLE forum posts were analyzed and frequency of posts in each category was identified. Analysis of the first two categories (*extent of participation* and *equal participation*) involves quantitative data while the last three categories (*extent of roles*, *reactivity to proposals* and *rhythm*) involve qualitative data.

The first indicator is the *extent of participation* (EXP). This indicator describes design team member's participation in quantitative dimension of MOODLE forum posts. To be an indicator of the extent of participation, the forum posts should initiate a discussion or at least should develop the design project for a better alternative solution (Pektas & Demirkan, 2011; Sagun & Demirkan, 2009). An effective forum post can be defined as a forum post that is segmented and classified as creativity category. The frequency of the forum posts for each team member is used in the analysis of the EXP.

Related to the group participation in an online design group, each team member should participate to sessions equally for increasing the effectiveness of the design team (Calvani et al., 2010). The *equal participation* (EQP) indicator is based on the frequency of the MOODLE forum posts. If one of the team members is monopolizing the design procedure and the other team members are not active enough, the design team is not well balanced (Soller, 2001).

For analyzing the *extent of roles*, *reactivity to proposals* and *rhythm* indicators, the MOODLE forum posts of the teams were coded using the Functional Category System (FCS) (Poole & Holmes, 1995). The coding system of design process activities is similar in application of the FCS by Jonassen and Kwon (2001) that were named as the communication patterns in-group problem solving activity. The communication acts related to design process were coded under eight phases named as: problem analysis (PA), problem critique (PC), orientation (OO), solution development (SD), solution approval (SA), solution critique (SC) and non-task (NT).

On the problem analysis (PA) phase the action is to state or define the problem. If the action is to evaluate the problem analysis statements, the problem critique (PC) phase occurs. If the action is to orient or guide the team process, it is defined as the orientation (OO) phase. Uploading the design files and their relevant ideas about design alternatives are grouped under the solution development (SD) phase. If the other team members support the uploaded solution it is solution approval (SA) or they may give new ideas or critiques for the development of the solution, it is solution critique (SC). Nontask (NT) phase is coded when the communication includes off-topic statements. The following Table 4 depicts the examples of the segments showing Functional Category System of design process.

After analyzing the MOODLE forums according to these phases, the phasic periods are identified. Three or more similar consecutive phases are considered as a phasic period. Each phasic period is composed of at least three sequential communication acts. As an example, if the phases are coded as PA, PC, PA, PC, PA, OO, OO, OO, PA, SD, SC, SD, SD, SD, the first phasic period begins with the sixth phase OO that has three similar consecutive phases and the second phasic period starts with the twelfth phase SD. The two coders independently categorized the design process phases within each team's MOODLE forum posts. They achieved an inter-rater reliability of 0.897 based on the segments of the forum posts. Amabile and Pillemer (2012) stated that the raters should be experienced in creativity domain and the acceptable inter-rater reliability should be 0.70 or higher.

Based on the analysis of collaboration action categories, the *extent of roles* (EXR) are found. In a design team, each student should not play the same role; each team member should be flexible in terms of giving critiques, drawing the design project and developing the presentation. Analyzing diversity of action categories (PA, OO, SD, etc.) in MOODLE forum posts for team members provided the data for this collaboration indicator.

For developing better alternative design solutions, proposal of new ideas or design critiques should be provided in a collaboration session by the team members. The design process occurs in cycles between the problem and solution phases and therefore orientation towards a solution is an important phase. The *reactivity to proposals* (REP) indicator is analyzed by using the number of orientation (OO), solution development (SD) and solution critique (SC) phases in the MOODLE forum posts for each team. The design process involves a social interaction among the team members as Schön (1983) named it as the 'reflection-in-action'. The team members reflect the action of each other in a design process. The collaboration among the team members is quite important for an effective design process. For each collaboration session, a regular and constant participation of the team members denote the *rhythm* of the design team (Calvani et al., 2010).

In the MOODLE forum posts, the frequency of each indicator is identified. According to the frequency of the indicators in each group, quartiles are decided. The points are attributed according to quartiles as the first quartile equals to 1 point, the second quartile equals to 2 points, the third quartile equals to 3 points and the fourth quartile equals to 4 points.

4. Results

This part consists of the results obtained from the protocol coding. The MOODLE forum posts and MSN messenger logs are used to gather data for the intra-individual creativity components and the social environment. The numerical and measurable data such as the frequency, time, participation levels, number of generated ideas and alternative solutions per one problem are revealed as the quantitative part and communication acts are revealed as the qualitative part.

4.1. Related to the quantitative data

In this part, the forum posts were analyzed to find out the collaborative and creative progress of each student. Each session of design communication was analyzed by using the forum post-time; continuous posts with 10 min delay of different design students were coded as a synchronous session. The design teams worked together in 51 sessions synchronously.

Table 5 shows the activities of the design teams. These activities include the total number of posts, sessions and synchronous sessions in design process and also the total number of generated ideas and sketches produced by each team. In the juries, the design team members were allowed to criticize the other teams as well as his/her team members.

Each week, the design students started a new discussion session in the design studio and continued it through the week. The MOODLE forum posts were mostly composed of design critiques, comments, questions and uploaded 2D or 3D drawings. Attendance to the MOODLE forums was not stable at the first and last weeks, as the design students generated more forum posts compared to the other weeks (Fig. 4).

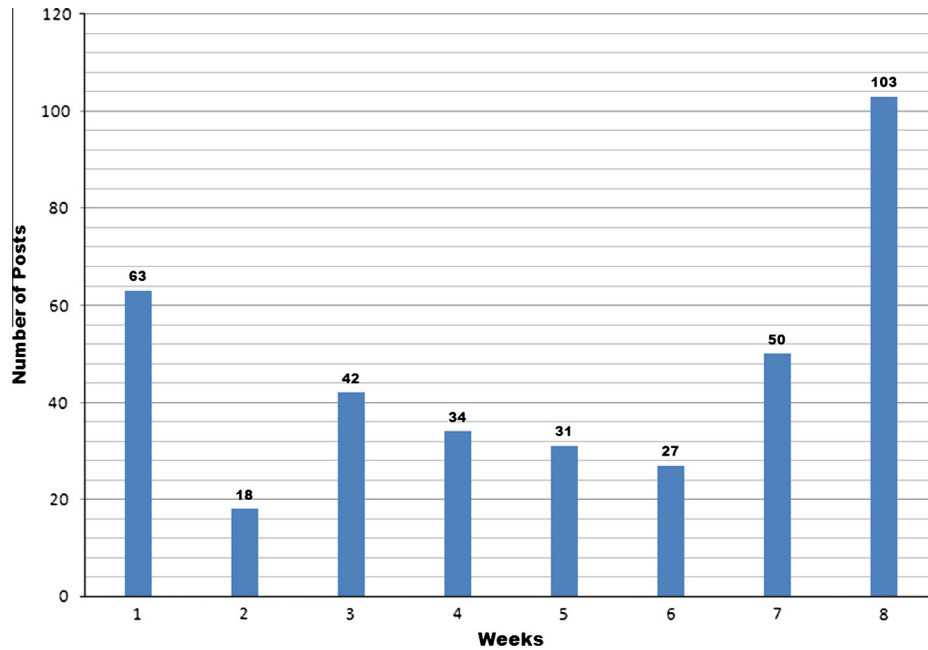


Fig. 4. Total number of forum posts through weeks.

4.2. Related to the qualitative data

The MOODLE forum posts were analyzed to find out the collaboration activities of the design teams as were stated in Jonassen and Kwon's (2001) study. The communication acts were coded under eight phases named as: problem analysis (PA), problem critique (PC), orientation (OO), solution development (SD), solution approval (SA), solution critique (SC) and non-task (NT). Each phasic period is identified with at least three sequential communication acts. There were no criteria development, solution critique and non-task phasic periods in this study.

The design team 1 created 8 phases, the teams 2, 7 and 8 each created 3 phases, the teams 4, 5 and 9 each created 1 phase and the teams 3 and 6 did not create any communication phase. The most occurred phase is the solution development phase. The problem critique and orientation phases occurred only in the design team 1. The longest phase was the solution development phase in the design team 8. The shortest phase was the problem analysis phase that occurred in the design team 9. Although the design team 1 created four different phases in their communication acts, the other design teams created only problem analysis and solution development phases.

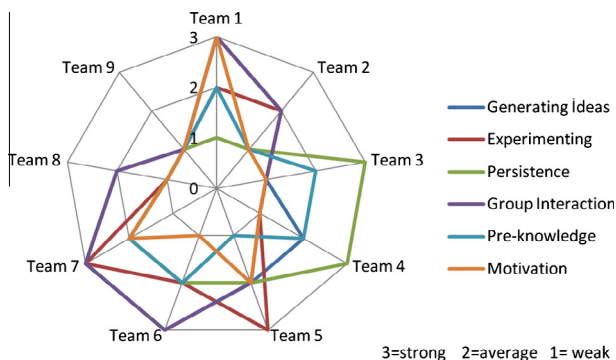


Fig. 5. Integrated radar graphic of the intra-individual creativity components of design teams.

4.2.1. Related to the intra-individual creativity components

The creative relevant processes component has three categories named as the *generating ideas*, *experimenting* and *persistence* (Fig. 5). The domain-relevant skills component has the *pre-knowledge* category and the task motivation component has the *motivation* and *group interaction* categories. To evaluate a design team's intra-individual creativity components, the MOODLE forum posts were analyzed and frequency of posts in each category was identified (Fig. 5).

The design team activities are identified as *strong* if there were 10 and more segments in the group communication. If a design team's communication includes 5–9 creativity indicators, the category is rated as *average*. The creativity indicators are rated as *weak* when 4 or fewer segments were identified in the design team communication.

According to Fig. 5, the design team 1 generated many design ideas; however, the persistence of the team was weak. Although communication among the team members was strong, they were not persistent on an idea for the final solution; they continuously changed their design solutions. On the other hand, the design team 3 generated fewer ideas than the design team 1. Since their persistence was strong, the design team 3 developed the design alternatives and finalized one as a design solution. However, their group interaction as well as their motivation was weak.

The design team 7 had the highest number of the creative relevant process (direct creativity indicators) segments and the design team 1 had the highest number of domain relevant skills and the motivation (indirect creativity) segments during the study. According to the findings of the intra-individual creativity components analysis, the design team 9 was the weakest team in the study.

4.2.2. Related to the social environment component (the collaboration analysis)

In order to analyze the social environment component, the MOODLE forum posts were identified for each indicator. According to the number of posts in each indicator quartiles were decided. Quartiles were graded from 1 to 4, 1 having the lowest number of segments. The integrated radar graphic shows all design team values according to the collaborative environment indicators

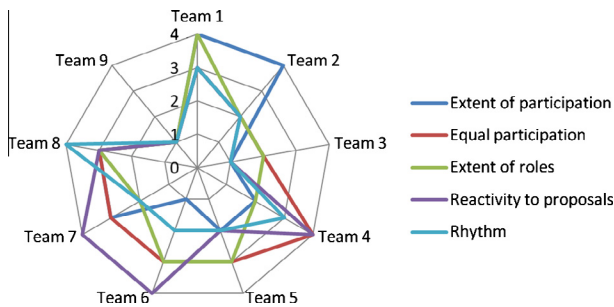


Fig. 6. Integrated radar graphic of the collaborative environment indicators of the design teams.

(Fig. 6). The graph demonstrates that the design teams 1 and 2 have a high level of extent of participation. Since the design team members of 4, 6 and 7 expressed their critical evaluations to new ideas and followed group discussions, their reactivity to proposals indicator values are 4. Only the design team 8 gets 4 points from rhythm because their number of collaborative sessions is higher than the other groups. According to Fig. 6, the equal participation is observed mostly in the design team 4. On the other hand, the design team 9 gets the lowest points from each indicator, since they did not show any collaborative activities throughout the study.

4.3. Correlations among the intra-individual creativity and the social environment components

The correlations among the intra-individual creativity components and the social environment components were analyzed using the interpretation of correlation categories based on Argyrous' (2011) work. As a social environment component, the *reactivity to proposals* category was highly correlated to the creative relevant process component – *idea generation* category (Kendall's tau $\tau = 0.752$, at 0.05 level) and the *task motivation* component – group interaction category (Kendall's tau $\tau = 0.752$, at 0.05 level) both belonging to the intra-individual creativity component.

Also, there are correlations among the social environment indicators. The *equal participation* component was highly correlated to the *reactivity to proposals* ($\tau = 0.767$, at 0.05 level) and moderately correlated to *rhythm* indicators ($\tau = 0.680$, at 0.05 level).

Besides, the correlations among design issues as number of sketches and design ideas produced with creativity components as intra-individual creativity and social environment were searched. The number of sketches was very highly correlated with the *reactivity to proposals* indicator ($\tau = 0.926$, at 0.01 level) and highly correlated to the *equal participation* indicator ($\tau = 0.811$, at 0.01 level) and moderately correlated to the *rhythm* indicator ($\tau = 0.575$, at 0.05 level) as the social environment components. Besides the number of sketches was moderately correlated to the group interaction category ($\tau = 0.626$, at 0.05 level) as the intra-individual creativity component.

The number of ideas produced in design process was highly correlated with the *equal participation* ($\tau = 0.789$, at 0.01 level), the *reactivity to proposals* ($\tau = 0.751$, at 0.01 level) and the *rhythm* ($\tau = 0.745$, at 0.05 level) indicators as the social environment components.

5. Discussion

5.1. On the interactions of the intra-individual components with the social environment components

The results showed that the social environment component named as the *reactivity to proposals* is closely related to *idea gener-*

ation as the creative relevant process component and *group interaction* as the task motivation component. Furthermore, Amabile and Pillemer (2012: 10) stated, "The social environment component, can influence each of the intra-individual components". Also, they added that experiencing, modeling and training could affect creativity relevant skills. *Reactivity to proposals* occurs as a 'reflection in action' in design through design critiques (Schön, 1983). It can be concluded that the creative relevant process component named as the *idea generation* could be affected as the designer gains experience in design process (Demirkan & Hasirci, 2009). Hirst et al's (2009) study also supported the findings of this study by concluding that individual learning through training and acquiring task specific skills can foster team creativity.

The social environment indicators named as *equal participation*, *reactivity to proposals* and *rhythm* were also correlated among each other. As stated in the previous design literature related to teamwork, designers have the opportunity of exchanging and sharing their ideas, have the benefit of defining the design problem from different perspectives by reactivity to proposals through critiques and providing many satisfactory design solutions (Demirbas & Demirkan, 2007). Each team member should participate equally to sessions in rhythm for increasing the effectiveness of design process. Also, Liu et al. (2011) found that in organizational settings the team's rhythm, as a regular and constant participation of team member, enhances the creativity activities among the team members. These three social environment indicators that are highly correlated among each other determine the quality of the critique sessions in a creative design process.

The number of sketches produced was correlated with the *reactivity to proposals* indicator, the *equal participation* indicator and the *rhythm* indicator as the social environment components. Besides the number of sketches was also correlated to the group interaction category as the intra-individual creativity component. Hasirci and Demirkan (2007) stated that sketches as the externalization of mental imagery are considered as the implicit parts of creativity for enhancing design studio process. Also, Calvani et al. (2010) stated that proposals of the team members should involve critical evaluations and argumentations. In a design process, the sketches provide a common ground for the interactions of the team members. As Bilda and Demirkan (2003) found a design medium should support the visual-spatial features and organizational relations of design for the production of alternative solutions to the design problem.

The *equal participation*, the *reactivity to proposals* and the *rhythm* indicators as the social environment components were highly correlated to the number of ideas produced in design process. The number of ideas increases in design process, if there is a tendency of producing more creative design solutions (Carroll, 1993). An increase in the number of ideas should provide a collaboration environment with equal participation of the team members through reflection in design process that occurs through design critiques among the team members (Sagun & Demirkan, 2009). Furthermore, the given critiques should be provided in rhythm among the team members. Therefore, it can be concluded that the critiques given to the team members either in written or drawing forms increased the number of design ideas while enhancing creativity in collaborative environments. In the design process, the most important design knowledge and ideas are acquired through self-reflection that is developed through design critiques (Demirbas & Demirkan, 2007).

5.2. Implications to design process

The findings of this study showed that *reactivity to proposals* component is closely related to *idea generation* and *task motivation* components. Therefore, the design process should provide the

reactivity to proposals act as defined as ‘reflection in action’ in design process by Schön (1983). Reflection in action is a process where knowledge is created through the transformation of ideas and experiences among the team members through critiques and comments. *Reactivity to proposals* occurs as an act that fosters creativity in design process through idea generation. Furthermore, *task motivation* that results in individual learning through training and acquiring task specific skills can also foster team creativity. The findings of this study is supported by Schön’s (1983) epistemological design education model in which design professionals acquire knowledge from tradition and experience, rather than science. Schön (1983: 299) defined the role of designer as an active “practitioner that becomes a researcher ... and engage in a continuing process of self-education”.

The *reactivity to proposals* act is performed through the given critiques in collaborative sessions. In collaboration sessions, the team members work together towards one common design idea and provide as many different ideas as possible. In these sessions, critiques may be given in text and/or drawing forms among the team members. Sketches drawn in collaboration sessions as the externalization of mental imagery are considered as the implicit part of creativity for enhancing the design process. Therefore, the sketches drawn in collaboration sessions should provide a medium in which designers see the emerging properties in sketches and elaborate on the design ideas based on them.

For enhancing creativity in design process, it is important to stimulate the designers for collaborative acts for increasing the number of critiques for the development of ideas as well as an increase in task motivation. Also, the team members should be encouraged to draw many sketches at various stages of design to have the opportunity of exchanging and sharing ideas for providing satisfactory design solutions. This study revealed that the role of sketching is an important issue in fostering creativity in a digital collaborative design process.

5.3. On the digital environment with the limitations

The technological support of the digital environment is an important issue in studying the social creativity domain. As Shneiderman (2007) suggested that collaboration-oriented tools have a positive influence on the social creativity. This study used the MOODLE and Google SketchUp as the social environment and concluded that the digital environment is a component that is related to the creativity in all levels. The digital environments helped the students in externalization their design decisions in sketches and drawings. As Fischer, Giaccardi, et al., 2007 stated externalizations support creativity by producing a record of mental imagery, moving from conceptual representation to concrete representations while collaborators share their sketches and drawings. Also, Hasirci and Demirkan (2007:269) concluded, “imagery alone cannot be sufficient to improve an idea, and good representational skills [that] are crucial in the developmental phases” of design.

Technical infrastructure is important for the creative digital environments; the broadband Internet connection and up-to date software and hardware enable more effective design process. There should be an integrated interface for the digital environments; the user interface should integrate communication and drawing/sketching tools. Also, the findings indicated that an integrated interface could result in a creative design environment while reflectivity to others’ work is enhanced.

6. Conclusion

The objective of this study was to explore the interaction of the four components of the creative process in design thinking – com-

posed of three intra-individual and one social environment component-in a digital environment. Findings indicated that the social environment component named as the reactivity to proposals is closely related to idea generation as the creative relevant process component and group interaction as the task motivation component. Furthermore, the design issues such as the number of sketches or design ideas produced in design process were also correlated to the social environment as well as to the intra-individual creativity components. It is concluded that sketching and the number of critiques are the two main issues to enhance creativity in digital collaborative design process.

On the methodological level, further research should be based on larger samples in various design institutions and different geographic regions, since this study was conducted with a limited number of students in one institution. This study focused on the interaction of creativity elements with the collaboration indicators in design process. Further study may be conducted on the analysis of final products and find the interaction of creativity elements with the collaboration indicators that result in more creative products. This would allow the researchers in better integration of the quantitative and qualitative analysis and to study the possible correlations among the creativity components and collaborative effectiveness indicators in the design process as well as in the designed products.

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