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The Influence of Design Methods on the Design Process: Effect of Use of Scenario, Brainstorming, and Synectics on Designing

Hsien-Hui Tang[a], Ying-Ling Chen[a] and John S. Gero[b]

[a]National Taiwan University of Science and Technology; [b] Krasnow Institute for Advanced Studies

This paper presents the results of protocol analyses of collaborative design sessions to examine whether the use of different design methods influences the design process. Nine collaborative design sessions using brainstorming, scenario, synectics were analyzed using the function-behavior-structure ontology. The frequencies and distributions of percentages of design issues and design processes were statistically analyzed to determine differences in the design processes caused by the use of different design methods. The results indicate that the use of different design methods influences the design process and the differences appear early on in the design sessions. Brainstorming was more oriented toward functional thinking. Scenario was more oriented towards the design of customer-oriented products by simulating various expected behaviors in context. Synectics was more oriented towards the thinking of product structures and their combination. When dividing the design sessions into three sections, it was found that the influences of the design methods were most pronounced in the early design stage of the conceptual design process. This research contributes to a better understanding of the use of design methods from a design cognition point of view.

Keywords : Design method; Design process; Protocol analysis; Function-behaviour-structure framework; Brainstorming; Synectics; Scenario;

Introduction

The direction for developing innovative products and service in a fast evolving and highly competitive industrial environment has been shifted from manufacturing and R&D focuses to a design-focused brand innovation era. Consequently, design has gradually become a popular and prominent major at schools. Amongst the courses young designers study, design method is a common compulsory course offered by industrial design faculty at universities. Its aim is to teach students how to develop a design project from the beginning to the end with appropriate approaches and techniques. They can help students develop critical thinking capacity as a conceptual aid for organizing the design process quickly and effectively.

This study is interested in how various techniques learned by students in a design method course can facilitate the process of product design. The major question is how different design methods influence the design process. The minor question is how different design methods fit into different stages of the design process.

Protocol Analysis

Protocol analysis, verbal reporting as data, has been widely applied in the design community as one of the research methods exploring the cognitive process of design (Cross, 2001; Cross, Christiaans, & Dorst, 1996).

Discussions of theory and operational techniques have been extensively published over the last decade or so (Foreman & Gillett, 1997; van Someren, Barnard, & Sandberg, 1994; Ericsson & Simon, 1993). Recent developments in knowledge and methodological improvements are scattered across different journal articles, books, and conferences (Cross, 2001, 2007; Cross, Christiaans, & Dorst, 1996; Michel, 2007; McDonnell & Lloyd, 2009).

Two protocol approaches have been developed: concurrent, and retrospective (Ericsson & Simon, 1993). In concurrent protocols the subjects are required to design and verbalize thoughts simultaneously (Lloyd, Lawson, & Scott, 1995). In retrospective protocols, subjects are asked to design first, and then retrospectively report the design processes, with or without visual aids. Studies of collaborative design have collected concurrent protocols in communication between members without compulsory thinking-aloud (McDonnell & Lloyd, 2009; Stempfle & Badke-Schaub, 2002; Turner & Turner, 2003).

The procedures of concurrent protocol analysis are videoing, transcription, segmentation, encoding, and analysis (Ericsson & Simon, 1993; Foreman & Gillett, 1997; van Someren, et al., 1994). Segmenting and encoding can be integrated into one step, in which coders simultaneously parse and encode the protocol.

Collaborative design studies have merited considerable attention (McDonnell, 2005; McDonnell & Lloyd, 2009). The various research methods used include ethnographic field research, case studies, interviews, linguistic analysis, and protocol analysis. An important research theme in collaborative design studies using protocol analysis is reflection-in-action (Adams, Turns, & Atman, 2003; Stempfle & Badke-Schaub, 2002; Valkenburg & Dorst, 1998).

Design Methods

Current design education provides many different design methods for students to learn and apply in their design projects (Cross,1989, Jones, 1992).

Brainstorming

Amongst different methods, brainstorming is the most used group creativity technique by which a group could generate a large amount of ideas in a short time and provoke divergent thinking in a team. It was developed and coined by Alex Faickney Osborn in 1953 through the book *Applied Imagination*. It published both the method and its rules. It is commonly believed that brainstorming can help to foster the atmosphere of creativity or innovation in a team with its freedom of proposing unusual and unconstrained ideas.

The greater the number of unusual ideas generated, the more the chances of having good design idea even within a limited time (Osborn,1963). Brainstorming helps participants to participate in a non-judgemental and non-egocentric atmosphere, being similar to the way children communicate, and to establish trust about the concepts through sharing them (Jones, 1992).

A successful brainstorming session needs an appropriate "host" to guide the process. It usually includes warm up, brainstorming, and evaluation (VanGundy, 1998). The downside of brainstorming is the lack of a macroscopic view to resolve complex problems or the problems requiring professional knowledge (Roozenburg & Eekels, 1995). Execution points of brainstorming are the following (Kelley, 2004): 1. One at a time, 2.Go for quantity, 3. Delay judgment, 4. Encourage wild ideas, 5. Build on others' ideas, 6. Focus on topics, 7. Be visual.

Scenario

Scenario is time-based narrative used to describe process, action, and snapshots of events (Campbell, 1992). It uses personal experiences to express the structure of a story through which designers can absorb and transfer related information internally or externally. It can be used to depict the implementation of advanced technology in fulfilling the users' life in the future (Nardi, 1992). It can play roles of communication and guidance to assist the coordination of the design process and situation (Carroll, 2000), and thus it is often used in industrial and service design to establish product image and bridge designers and managers in communication. It provides links and language for multidisciplinary collaborative design team.

IDEO has been promoting Scenario as a design process in practice and emphasizes the importance of the concept of "user-centered" design. In practice, Brown (2009) regarded the primary principle of scenario as the relaying of concepts based on partners' opinions. In his company, IDEO, the practical implementation of scenario was through using a large amount of Post-It stickers on almost every wall in the meeting room.

The procedure of using Scenario is 1. understand, 2.observe, 3.visualize and predict, 4.evaluate and refine, 5.implement. The use of scenario often includes information collection through observation, establishing user needs and product insights through understanding user behaviors and intentions that they are not even aware of, and having empathy to place oneself into someone's shoes to design product, service, system and interaction (Brown, 2009). Storyboards, snapshots, 5W1H are often used to illustrate the context where users interact with designed artifacts.

Execution points of Scenario are the followings:

1. Set up target users and their characteristics and explore their needs and wants
2. Using visual brainstorming to explore the relationship between users and products

3. Describing key HCI process including 5W1H
4. Depict the major scenarios from which critical issues and key ideas are generated
5. Generate details through critical issues and key ideas

Synectics

Synectics is a systematic problem solving methodology that stimulates thinking processes via metaphor and analogy and emphasizes the importance of integration of individual opinions. It was developed by George M. Prince and William J.J. Gordon in the 1950s. (Gordon,1961).The methodology has evolved substantially in the ensuing 50 years (Nolan, 2003).

The main idea is to link initially unrelated issues together to change thinking models and then produce new concepts. During the process, random text tables, dictionaries, newspapers could be utilized as aids to provoke associations and multiple links. These associations and links were originated from mostly physical objects. Synectics enables every member of a team to contribute to the results with his/her own background. Its major difference from brainstorming is the directional guidance provided by four kinds of analogy (Jones, 1992).

The execution points for Synectics are the followings:

1. Decompose design topic into isolated elements to make the familiar strange
2. Use metaphor to analyze design topic。
3. Look for alternatives to replace isolated elements using four kinds of analogy: personal analogy, direct analogy, symbolic analogy, and fantasy analogy
4. Reassemble alternatives and elements into different combinations to make the strange familiar
5. Evaluate different combinations by experts

These three methods were chosen to compare in this study because of the wide use of them in design practice and education. They cover rational and creative design processes and emphasize both users and artifacts being designed.

The Function-Behavior-Structure Model

The Function-Behavior-Structure (FBS) model of designing was initially developed by Gero and his colleagues (Gero, 1990; Tham et al., 1990). The elements of the model have been extended to cover broader cognitive issues (Gero & Kannengiesser, 2004). For example, the FBS model has been adapted into a descriptive model that integrates the design process with processes from cognitive psychology. The model links different operations to types of outcome from both disciplines (Howard et al., 2008). FBS as both prescriptive and descriptive models have been extensively discussed (Vermaas & Dorst, 2007). As a result, the FBS model is one of the representative models that could be utilized in understanding the design process and can be used as an ontology of designs and designing.

This study applied the FBS ontology as the coding scheme. To apply the function-behaviour-structure ontology in encoding the protocol, the transcripts have to be parsed into segments and coded according to the designers' intentions (Ericsson & Simon 1993; McNeill et al., 1998). Details of the ontology are shown at Figure 1 and elaborated further in the next section. This FBS ontology has been applied and compared in different disciplines (Kruchten, 2005).

Design Issue

The FBS ontology of design uses the concept of design issue as the basic unit of its ontology and defines six foundational non-overlapping design issues (Gero & McNeill, 1998). The ontological variables that map on to design issues are: function, behavior, and structure plus design description, Figure 1. Outside the direct control of the designer is the set of requirements, labeled R, provided by the client. The function (F) of a designed object is defined as its teleology; the behavior (B) of that object is either derived (Bs) or expected (Be) from the structure, where structure (S) represents the components of an object and their relationships. In terms of encoding, function corresponds to the users' needs, the service the system will provide, i.e. the purpose of the artifact. Behavior corresponds to the system's expected and actual performances, ie how the system and its sub-systems work. Structure corresponds to the resulting forms of the designed artifacts in terms of its elements and their relationships. Therefore, any design utterance or activity fits into one of these six categories, namely, functions (F), expected behaviours (Be), structure behaviours (Bs), structures (S), Descriptions (D), and requirement (R) (Gero, Kan, & Pourmohamadi, 2011).

Design Process

From an ontological view, the aim of designing is to transform a set of function issues into a set of structures and finally document them as a set of descriptions. However, there is no direct route from functions to structure. Instead, the designer goes through a series of transitional processes between different issues to reach a final design. The transition from one design issue to another is a design process. Figure 1 shows the relationships of the six design issues and resulting eight design processes, numbered 1 through 8.

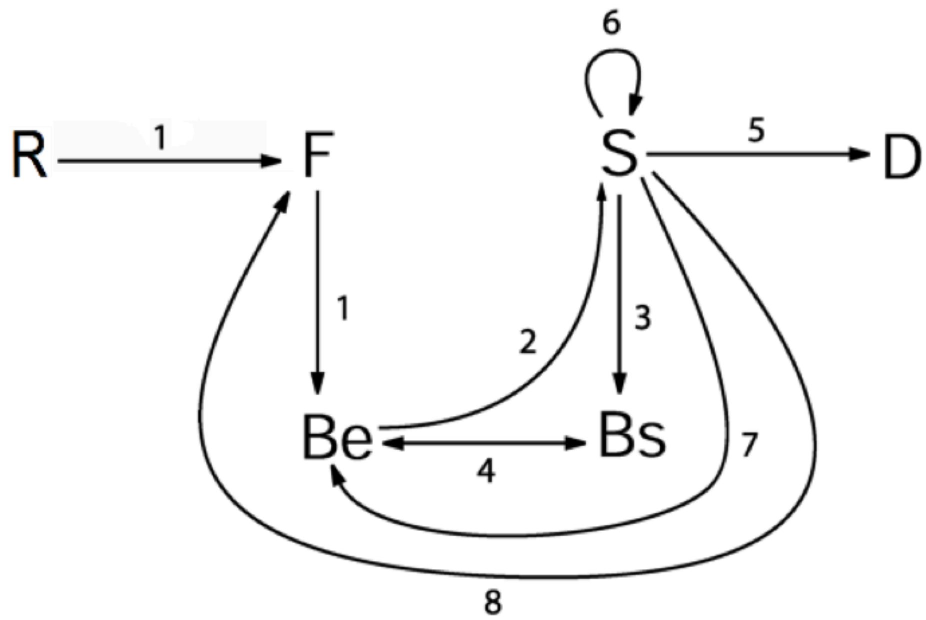

Figure 1. Design issues, labeled with symbols, and resulting design processes, numbered 1 through 8, defined by FBS ontology of design (after: Gero et al 2012)

Formulation (R→F, F→Be), labeled 1 in Figure 1, is the design process of producing a set of expected behaviours from the requirement and function issues. The design process synthesis (Be→S), labeled 2, is the design process of generating structure issues from the expected behaviours. The analysis process (S→Bs), labeled 3, occurs when a set of behaviours are deduced from the structure issues. The evaluation process (Bs→Be, Be→Bs), labeled 4, of the ideated structures is produced when comparing the expected and structure behaviours. The documentation process (S→D), labeled 5, can be of the structure or the externalization of any design issue. In addition to these processes, the FBS ontology of design has three types of reformulations. These processes are aimed at capturing the actively changing state of the design and accounts for changes in structure, behaviour or function issues. The processes are respectively called reformulation-1 (S→S), labeled 6, reformulation-2 (S→Be), labeled 7, and reformulation-3 (S→F), labeled 8, in Figure 1.

Based on the FBS coding scheme, two types of transition processes can be generated from any coded protocol: semantic and syntactic design processes. In the semantic approach, coded segments of the protocol are connected by their semantics which generates a link between them and depending on which design issue is at each end of the link a particular design process is produced. This kind of linking generates a semantic linkograph.

The syntactic approach is based on a weaker model of design activity and relies on the sequential order of the design issues to generate the links between and to produce the design process, which is called the syntactic design process. Here each segment is linked to its immediately preceding segment. Depending on which design issue is at each end of the link a particular design process is produced. This kind of linking generates a syntactic linkograph.

We employ the syntactic approach in this research to produce the syntactic design processes of the participants in each protocol.

Hypotheses

Based on the definitions of the three design methods and FBS ontology, we proposed hypotheses regarding how the distributions of design issues and design processes might change as a result of the use of different design methods.

In terms of design issues we propose three hypotheses:

D1. Brainstorming has more function design issues than synectics and scenario because brainstorming is about generating a large amount of conceptual ideas without thinking whether they are important or useful.

D2. Scenario has more expected behavior design issues than brainstorming and synectics because scenario emphasizes the possible behaviors of users in context.

D3. Synectics has more structure design issues than brainstorming and scenario because synectics uses the combination of isolated elements as a way to generate new objects.

In terms of design process we propose three hypotheses:

P1. Brainstorming has more formulation (R→F, F→Be) than synectics and scenario because brainstorming generates many ideas that are extended or examined by how people may respond to them.

P2. Scenario has more evaluation (Bs→Be, Be→Bs) than brainstorming and synectics because scenario helps to illustrate and consider how users' behaviors may interact with the objects' responses.

P3. Synectics has more analysis (S→Bs) than brainstorming and scenarios because synectics require users to evaluate the behaviors deduced from the structures of combined elements.

In terms of design stages, this paper hypothesizes that using these three design methods may result in the differences of the distributions of design issues and processes in the early, middle, and later parts of a design session.

Process

This research examined design teams that used these three design methods to explore the influences of design methods on the design process in three steps. First, we conducted collaborative design experiments. Second, two coders encoded the protocols, transcribed from the conversations in the collaborative design process, with the corresponding sketches and video clips by using the Function-Behavior-Structure ontology as the coding scheme to decode the design process in revealing the changes of design issues and processes.

Experiment planning

The twenty-seven participants were sophomores at the Department of Commercial and Industrial design in National Taiwan University of Science and Technology. All were majors in industrial design. Half of them were male, and half were female. They were grouped with familiar classmates into nine teams of three. Each team applied one method to design a water bottle that can protect users as an exam in the end of their compulsory course of design method where participants learnt brainstorming, synectics, and scenario design methods.

The averaged scores of major design course of teammates were used as the reference to allocate design methods.

Each team used sketches to collaborate face-to-face in a classroom at school. Two digital cameras recorded the whole design session: one for a microscopic view for sketching activities of the team on the table, and one for a macroscopic view for discussions and interactions between participants.

During each experiment, researchers first gave a brief about the chosen design method and the experimental process. Then, each team had sixty minutes to finish the design project and an additional 10 minutes to prepare a 3-minutes final presentation. During the final presentation, each team faced a camera to present their main idea using ideas and scenario sketches. This recorded presentation and sketches produced during the design process were used to evaluate their design outcome by judges. Additional information about the design problem was provided.

Three design professors in the faculty were invited as judges to score their final design outcome according to their A3 posters, sketches, and video clips in terms of innovation, function, and aesthetics.

We used protocol analysis as the research method to investigate the effect of adopting different design methods by industrial design students on the design process. The Function-behavior-structure ontology-based coding scheme was employed to produce data to comprehend the thinking structure of the participants and to further examine whether the design method is responsible for inducing differences in design thinking.

Each segment of protocol was encoded as one of the six kinds of design issues: requirement, function, expected behavior, structure behavior/behavior from structure,

structure and description. The syntactic links was encoded as one of the eight kinds of design process: formulation, synthesis, analysis, evaluation, documentation, reformulation 1, reformulation 2, and reformulation 3. Due to the various lengths of design processes, the numbers of design issues and processes were normalized by converting them into percentages. Before calculating the percentages, we deleted utterances that could not be categorized into the six kinds of design issues and the design processes that could not be categorized into eight kinds of design processes in the FBS ontology. Further, when more-than-three contiguous design issues of the same kind occurred they were collapsed into two adjacent design issues, for example, SSSSSS became SS. The effect of this was to remove multiple contiguous design issues and multiple contiguous design processes.

In the following section, we use the differences of percentages obtained from the results of using the three design methods to test our hypotheses.

Results

The averaged percentages of design issues were calculated in terms of design methods and plotted as bar charts, as shown in Table 1 and Figure 2. The results indicate the following:

1. Brainstorming had the highest percentage of function design issues; this provides support for hypothesis D1.
2. Scenario had the highest percentage of expected behaviour design issues; this provides support for hypothesis D2.
3. Synectics had highest percentage of structure design issues and structure behavior design issues; this provides support for hypothesis D3.

Table 1.
Averaged Percentages of Brainstorming, Scenario, Synectics Design Issues

Methods	*R*	*F*	*Be*	*Bs*	*S*	*D*
Brainstorming	3.29	15.44	20.5	12.16	36.28	12.34
Scenario	3.17	8.7	33.38	14.37	32.94	7.43
Synectics	8.34	6.62	22.05	15.97	40.51	6.52

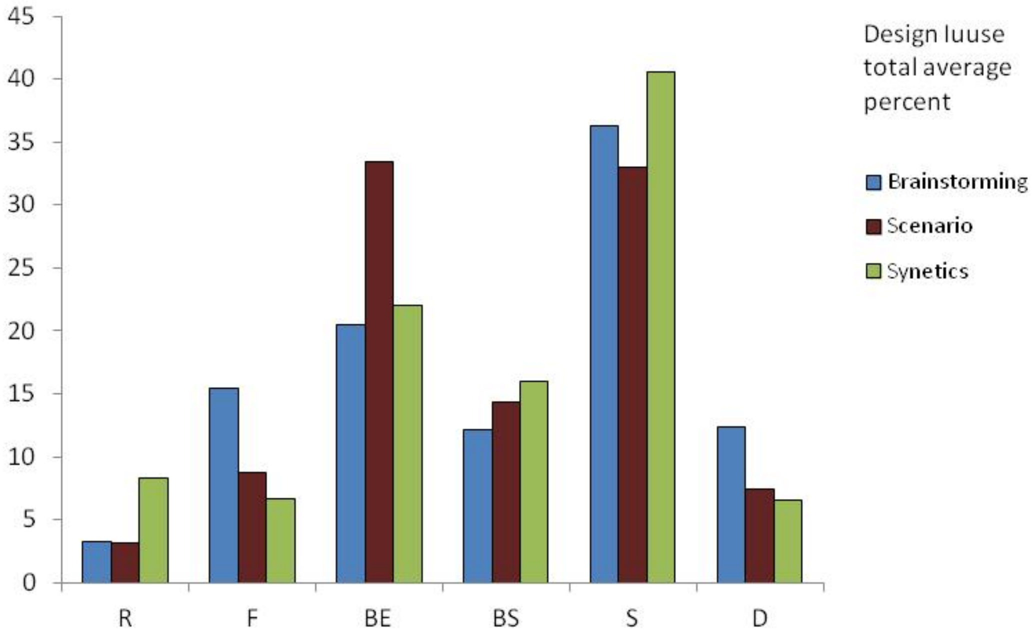

Figure 2. Bar Charts of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of FBS Design Issues

The averaged percentages of syntactic design processes were calculated in terms of design methods and plotted as bar charts, as shown in Table 2 and Figure 3.

Table 2.
Averaged Percentages of Design Processes for Brainstorming, Scenario, and Synectics

Methods	*F-Be*	*Be-S*	*S-Bs*	*Be-Bs*	*S-D*	*S-S*
Brainstorming	16.3	14.36	9.94	3.59	4.97	26.24
Scenario	11.76	15.09	13.81	3.58	3.32	30.18
Synectics	10.57	17.24	15.17	2.76	2.53	30.8

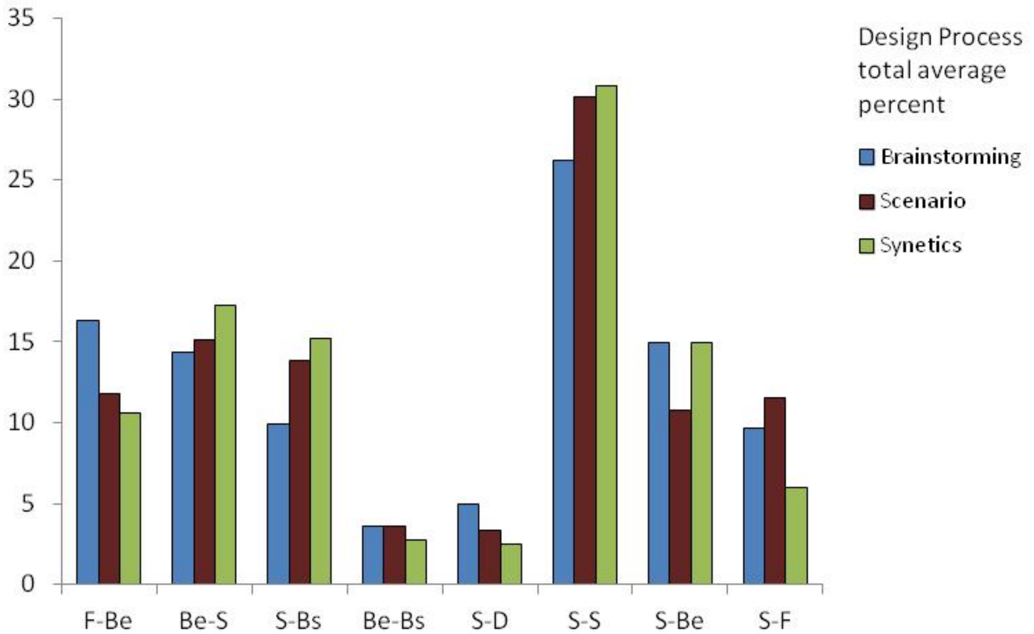

Figure 3. Bar Charts of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of FBS Design Processes

The results indicate the following:

1. Brainstorming had the highest percentage of formulation design process (F-Be); this provides support for hypothesis P1.

2. Scenario and brainstorming have higher percentages of evaluation design process (Be-Bs) than Synectics; this provides only partial support for hypothesis P2.

3. Synectics had the highest percentage of analysis design process (S→Bs); this provides support for hypothesis P3.

Examining Design Sessions in Detail

In order to obtain a more detailed understanding of the effects of different design methods on the design process, each design session is divided into three thirds of equal numbers of segments. This provides the opportunity to observe differences that occur across time during a design session. The percentages of the design issues of the three teams using the same design method are plotted as box-charts for each third. Figures 4, 5 and 6 show the results for first, middle and last thirds respectively.

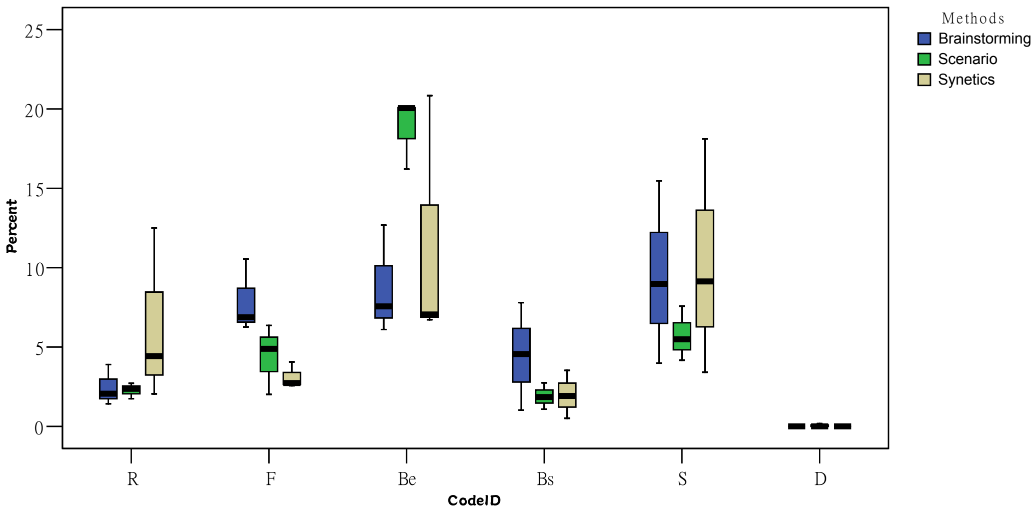

Figure 4. Box Plots of Distribution of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of FBS Design Issues During the First Third of Design Sessions

It can be observed that all differences in design issues occur early in the design sessions and the differences gradually diminish toward the end of the design sessions. The first one-third of the design sessions showed the biggest differences between different design methods, where the findings about design issues were observable. The brainstorming sessions had more function, the scenario sessions had more expected behaviors, and the synectics sessions had more structure, as shown by their means in Figure 4.

In the middle one-third the differences were smaller. In the last one-third the differences were no longer observable**. T**eams using different design methods produced similar distributions of percentages of design issues except of documentation, as shown in Figure 5 and 6.

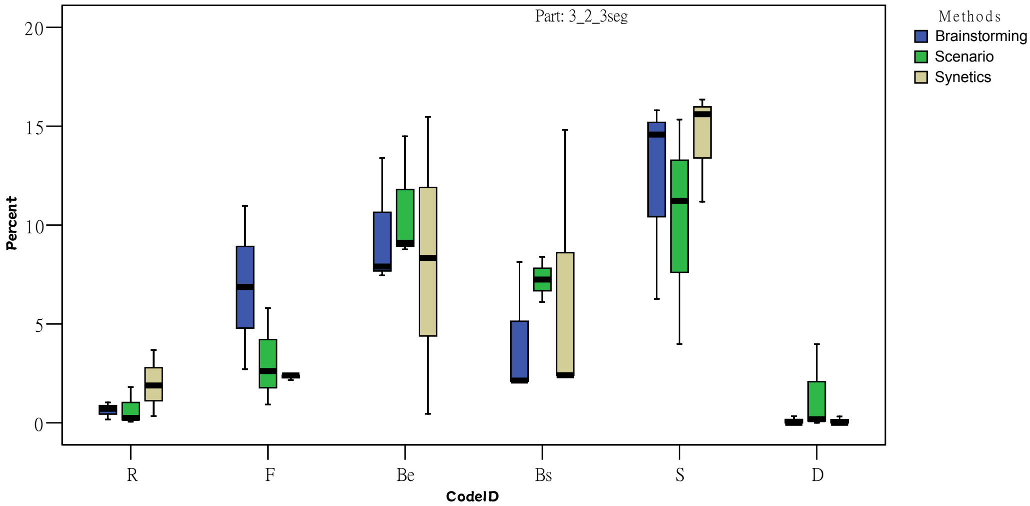

Figure 5. Box Plots of Distribution of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of FBS Design Issues During the Middle Third of Design Sessions

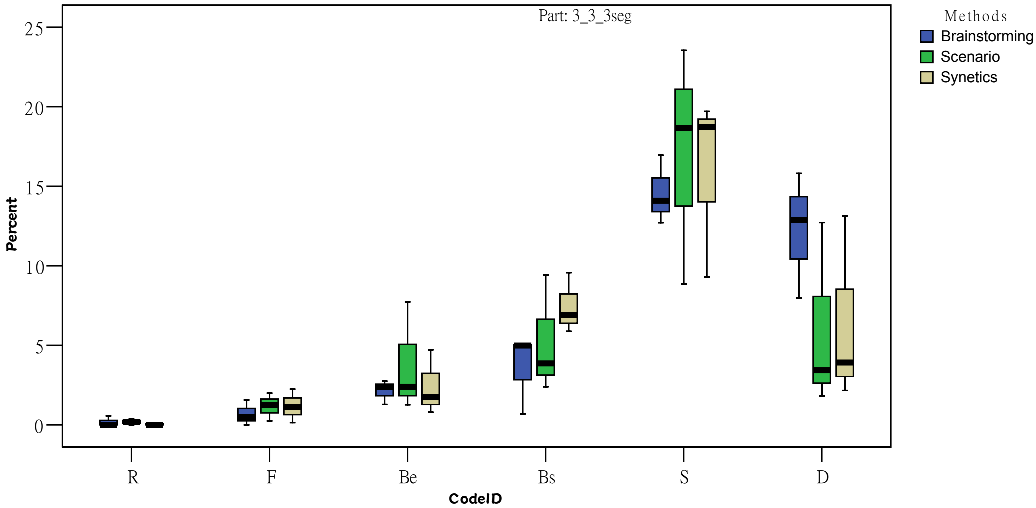

Figure 6. Box Plots of Distribution of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of FBS Design Issues During the Last Third of Design Sessions

The differences between different design methods were not observable in terms of the design processes as a whole. Therefore, the design sessions were divided into three sections by number of segments and are shown as box plots in Figures 7, 8 and 9. There were few observable differences except in reformulations: reformulation-1 and reformulation-3 in the first third, reformulation-1 and reformulation-3 in the middle third, and reformation-1 and reformulation-2 in the last third.

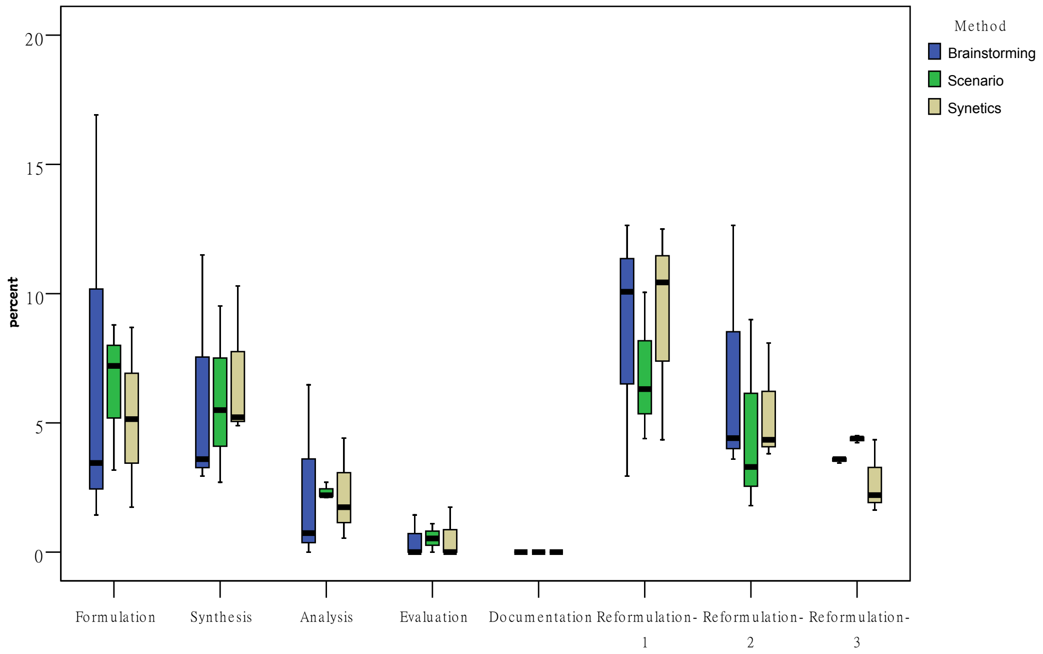

Figure 7. Box Plots of Distribution of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of FBS Design Processes During the First Third of Design Sessions

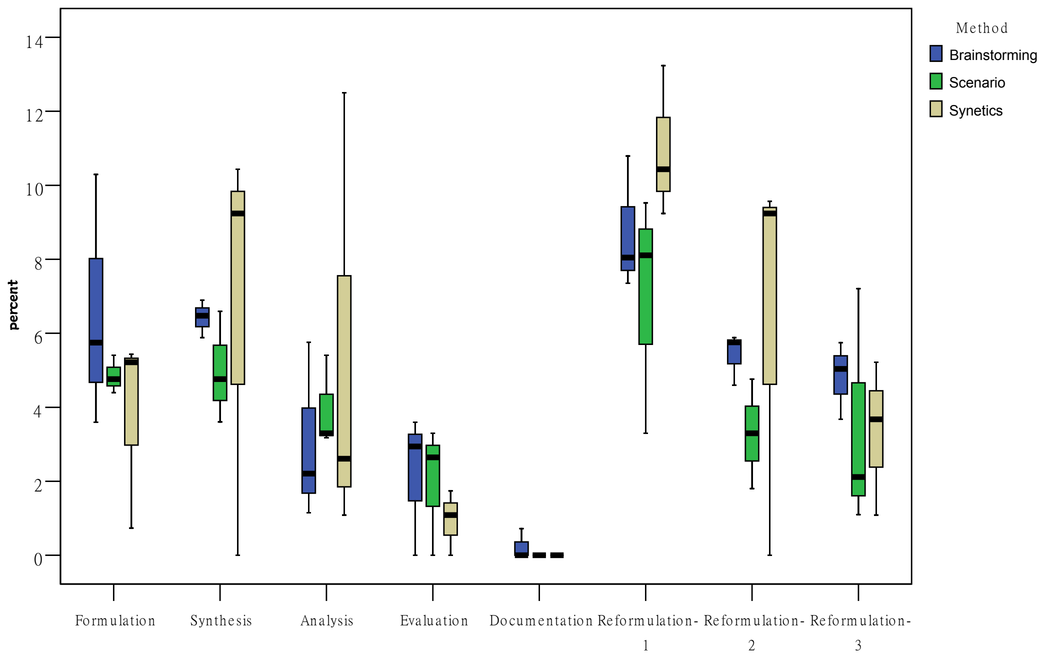

Figure 8. Box Plots of Distribution of Averaged Percentages of Brainstorming, Scenario, Synectics Design Processes in Middle Third of Design Sessions

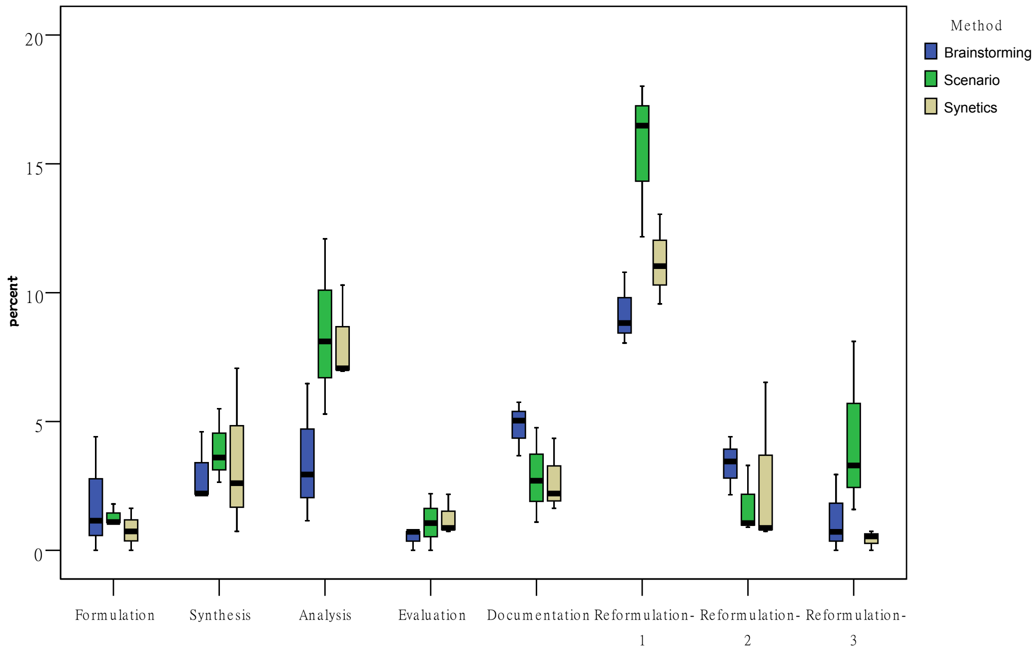

Figure 9. Box Plots of Distribution of Averaged Percentages of Brainstorming, Scenario, Synectics in Terms of Design Processes During the Last Third of Design Sessions

These differences in reformulations imply that different design methods affect reformulation differently. Further research is needed to elaborate this.

Conclusions

Protocol analysis of collaborative design sessions were conducted to examine whether the use of different design methods influences the design process. Nine collaborative design sessions using brainstorming, scenario, synectics were analyzed using the function-behavior-structure ontology.

The main conclusions are the use of design method does influence the design process and the differences appear early on in design sessions.

Brainstorming was more oriented toward the functional thinking category. Scenario facilitated the design of customer-oriented products by simulating various expected behaviors in context. Synectics enhanced the thinking of product structures and their combination. These findings correspond to our hypotheses about these design methods from literature reviews and practical experience.

Based on their characteristics, we could arrange these three methods into different stages of the design process to utilize their abilities best. This may yield a new direction to apply design methods and to explore the potentials of design methods.

Therefore, a good use of the features of these design methods can help designers to enhance different aspects of ideation. Assuming the results and protocol analysis data of this study are supported by a larger study, they can be used as a reference for design education and design thinking.

Acknowledgments

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