Theoretical Background of an Early Prototype Use in Cross-functional Collaborative Design Context

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Abstract: This paper is about understanding how to conduct more effective collaborative design activity with a prototype in the early design process. Traditionally, prototypes have been employed as a method to test and evaluate a certain aspect of proposed design concepts. Currently, there is a new attempt to use a prototype as a tangible medium to increase the chance of creating innovative design concepts and different knowledge sharing in a cross functionally collaborative design context. However, bringing experts together in the context does not guarantee a successful collaboration if their ideas, perspectives, and knowledge are not properly shared with each other. To improve the situation, this paper proposes a method, called "CFCP (Cross-functional Collaborative Prototype)", and attempt to develop fundamental backgrounds such as its definition, the modes of actions, and practical procedure to foster the cross functional collaboration in the early design stage. We believe this study will help to employ and manage coherently for diverse design groups that wish to use prototypes in an early, collaborative design situation in their organizations.

Key words: Cross- functional Collaboration, Early Prototyping, Activity Theory.

1. Introduction

A prototype usually is employed in the middle of a design process after product specifications or concepts are defined. More specifically, a prototype mostly turns design concepts already in place into a realized form in order to assess the appearance, function, or drawbacks of a product being developed or to discern the preferences of those involved. Recently, however, some innovative design groups have recognized its capacity for contributing to effective team collaboration and concept generation at an early design stage. For example, IDEO, one of the largest and best-known product design firms in the U.S., encourages a playful and collaborative prototyping culture at the beginning of their design processes [1]. In addition, Leonard-Barton stresses that prototype should be used as a vehicle for facilitating cross-boundary communication which provide a lot of opportunities and potentials for innovation [2]. Despite of these emerging attempts to use prototypes in cross-functional collaboration in early design process, few serious attempts have been made to investigate its fundamental backgrounds to apply the method more effectively.

In this paper, we insist that a true collaboration usually comes with mutual benefits which often occur when each participant reciprocally learns something from each other [3]. In addition to the positive responses of mutual agreements, participants with diverse backgrounds cannot help but express the negative response of contradiction, conflict, misinterpretation, different opinions etc. However, it is also true to say that the negative tensions can also be a source of change and innovation. Although negative responses are often believed to create negative impacts on the design process, they also offer the potential to become a driving force for positive momentum which is a driving factor to move the team's design work forward to the next stage. Then, a critical question will be how to transfer the negative tensions to the positive momentum? This is juncture where CFCP comes into play.

With theses notions in mind, a CFCP that we propose in this paper is a tool to resolve conflicts among diverse perspectives, to give rise to positive momentum and ultimately increase effective team collaboration. Figure 1 shows a way to conduct an effective cross functional collaboration by applying CFCP method.

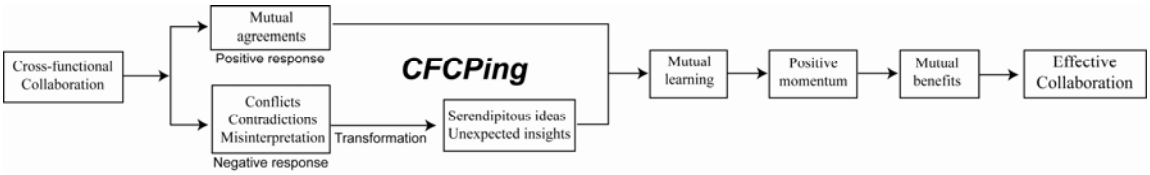

Figure 1. CFCP to Conduct an Effective Collaboration

2. Definition of CFCP

This chapter explores CFCP in terms of its definition by identifying key attributes of the terms. Because a CFCP is a compound word that consists of three words, cross-functional, collaborative, and prototype, it is necessary to provide the definition of each simplex word and then combine them in a meaningful way to obtain the definition of CFCP. Based on synthesizing the relevant attributes of the each word identified in the WordNet database [4], a CFCP can be literally defined as "a tangible, visible man-made creation to study, test, and display something that resulted from a diverse group of participants' joint mental activity" [5]. This definition clearly indicates three important aspects of CFCP. First of all, "Tangible and visible man-made creation" suggests that a CFCP should provide a structural form of ideas for its audience, so that they can physically interact with it. Tangibility and physicality allow people to have hands-on experiences and physical interaction with design ideas. Second, "study, test, and display something" refers to learning by doing and stresses the fact that a CFCP should be used to help team members learn about others' knowledge and to experiment their understanding. Finally, "resulted from a diverse group of participants' joint mental activity" refers to the fact that the desired outcome of a CFCP is tangibly integrated multiple perspectives and ideas which will create a positive momentum originating from reciprocal learning. In this sense, a CFCP plays the role of a kind of bait, leading people on the team to think of different ideas that may enable them to continuously extend ideas [6]. In addition, re interpretations of the original intention of a CFCP by others in team collaboration can trigger serendipitous idea generation, soliciting questions, or comments such as "What if we did it this way?", What about combining this idea with that? etc.

In summary, a CFCP is a physical representation of group design activity that enhances creativity, facilitates reciprocal knowledge sharing, and ultimately helps to increase the team's positive energy. Based on this understanding, a CFCP can be explained as a combination of three kinds of prototypes: a conceptual prototype to

express an individual member's novel ideas, a behavior prototype to obtain an experiential aspect and make critical observations while they are interacting with a prototype, and a collaborative prototype to establish key challenges and opportunities for the given project in a collective manner (Figure 2).

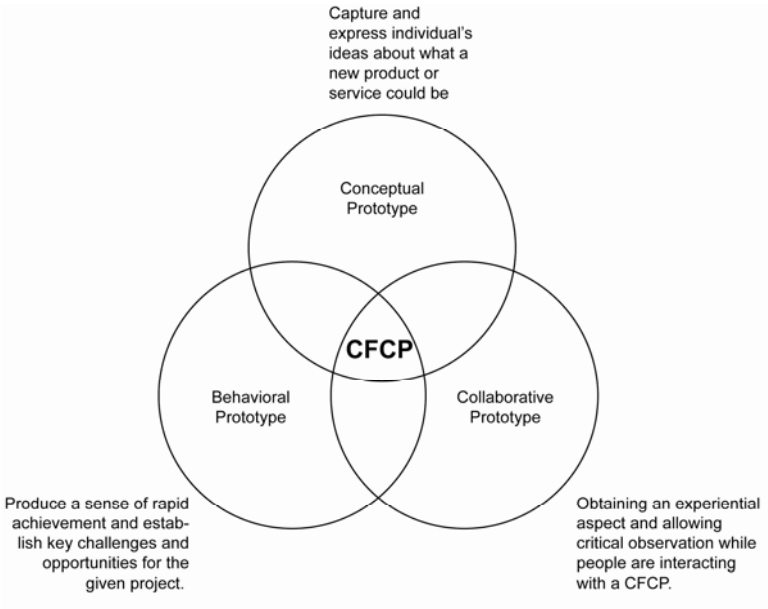

Figure 2. CFCP as an Intersection of Conceptual, Behavioral and Collaborative Prototypes

3. Three Modes of Actions for Fostering a CFCPing Activity

3.1 Ideation

The first mode of action, ideation, is about creating and generating ideas. Asking questions, discussing aspects of the existing product and current users' behaviors, and analyzing problems and wish lists with other participants are important activities for ideation. People in team collaboration, for example, become involved in this mode intuitively and come up with interesting ideas through the process. Some attempt to figure out why the current product had been designed in that way or bring out issues such as the current problems, benefits and needs by analyzing and sharing their different experiences and domain knowledge.

This observation suggests that collaboration in design should begin with asking questions about others' experiences and perspectives, and sharing them with each other. In this situation, existing products, related anecdotes, or reports (e.g. census) could be used as resources. Naturally, active user involvement in the ideation mode gets critical because this opportunity can be taken to identify users' latent needs and specific requests, and to reveal market opportunities [7]. The process of ideation would also be more productive when people physically interact with a tangible artifact which helps to share different perspectives for discussion. In addition, swift realization of their perspectives and thoughts is critical in getting immediate feedback and promptly refining their discussion in a group collaborative situation. As Csikszentmihalyi said [8], "Originality, freshness of perceptions, and divergent-thinking ability are all well and good in their own right, as desirable personal traits. But without some form of public recognition they do not constitute creativity," maintaining mutual interactions between personal and group perspectives is crucial in the ideation mode.

3.2 Embodiment

The second mode of action facilitating a CFCPing process is embodiment, an externalization process of an individual's internal thoughts and ideas with a certain structure. Embodying ideas is important because ideas are a fragile and ephemeral entity that easily and quickly disappears. Without embodiment, ideas might stay in one's mind and would be difficult to explain to others. In general, embodiment is usually understood as a skill-based action that requires technical skills for building something tangible and physical. A lack of fabrication skills tends to erect a cognitive barrier for those who do not have these capabilities. However, embodiment in CFCPing process is the act of sharing ideas with others through tangibly made prototypes.

In addition, embodiment of an idea could trigger new ideas and elicit questions that merit further investigation. People often come up with a novel idea while interacting and playing with a prototype. Once the initial idea is tangibly presented through prototypes so that people are able to see, touch, and play with the idea, people start to voice their own ideas to judge and improve the concept. Thus, embodiment in CFCPing process should not be only about fabrication of a tangible form of ideas but also manipulation of ideas to explore, examine, and test them. Such behaviors extend the application of CFCP not just as a representation of team's intended subject matter, but also as an embodiment of unintended potentials that may possibly turn out to be an appropriate solution idea during a design process.

3.3 Critiques

Once an idea is embodied in a physically contactable form that can give people something real, the last mode of actions, critique, is accelerated. During this mode, people debate and argue about possibilities, limitations, problems, potentials, as well as conflicts to refine suggested ideas and narrow down to specific solutions: Prototypes give everyone an opportunity to recognize and trust others' ideas. In this situation, people can learn about others' opinions and perspectives, reduce mis understanding of a given idea, and eliminate conflicts. Therefore, critique involves envisioning the future state of the design by reflecting on the current situation.

In sum, we suggest that the three modes of actions properly done will increase the efficiency of mutual learning in cross-functional collaboration if they are interchangeably iterated during an entire CFCP process.

3.4 Information and knowledge Flow in the Three Modes of Actions

The diagram in Figure 3 represents information and knowledge flow among the three modes. It shows that the flow starts from the mode of ideation (I), which is a process of transferring "an individual's internal and domain knowledge" to "explicit information" through mutual information sharing with others. In the mode of embodiment (E), "the explicit information" will be turned in to "experiential information" through mutual experience sharing with others in a team. During the embodiment process, a great deal of "experiential information" is accumulated and becomes "collective knowledge," defined as "the accumulated knowledge of the organization stored in its rules, procedures, routines and shared norms which guide the problem-solving activities and patterns of interaction among its members" [9]. Finally, through careful processes of critique, "the collective knowledge" will be transformed to "distributed knowledge," defined as "all the knowledge that a community of agents possesses and might apply in solving a problem" [10]. Then, the distributed knowledge can, in turn, be accumulated as an individual's internalized knowledge. Thus, the iterations of the three modes of actions are critical for turning an initial idea into more appropriate and clearer product concepts. If one of the

modes is missing or poorly performed during a collaboration process, its outcome would be less useful and its process might not be so productive.

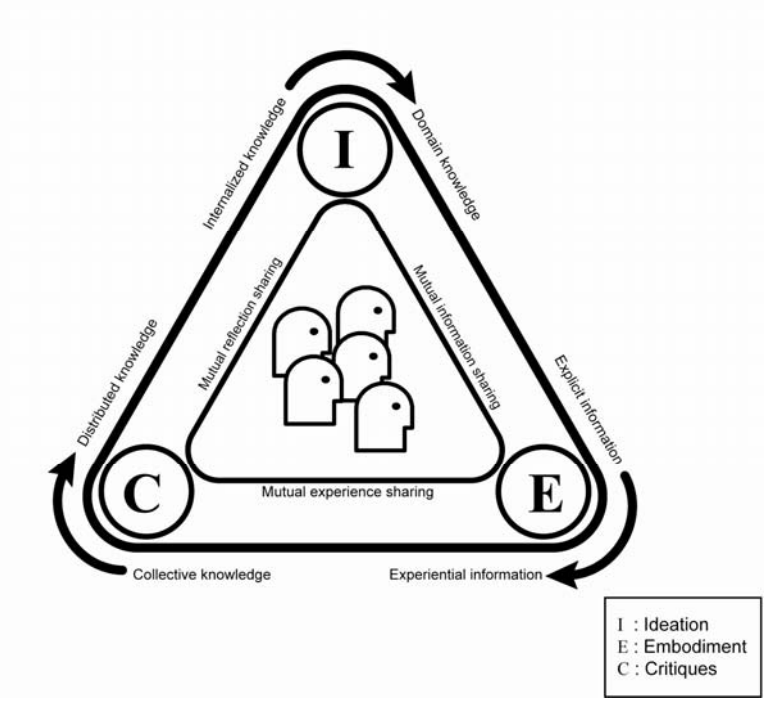

Figure 3. Three Modes of Actions for an Effective CFCP Process

4. Structure of a CFCPing Activity

Activities with CFCP (CFCPing) are viewed as a structured entity with distinct subcomponents to their roles, rather than as one monolithic structure. In addition, it is assumed that a structured CFCPing activity requires mutual interactions among its components in order to be effective. Looking at CFCPping activity in this way will aid in conducting the process, because designers will know what roles each component play. In this study, we adopt a conceptual framework from Activity Theory to view the essential components of a CFCPing process and their relationships.

Activity theory was initiated by a group of Russian psychologists in the 1920s and 1930s. The basic tenet of this theory is that all human activities are mediated by artifacts such as tools, language, or signs, among others, and that these artifacts mediate our relation with other human beings. Particularly, we adopt the concept of the second and third generation of activity theory by Engeström which focus more on social and cultural interactions. We insist that the theory will provide an appropriate conceptual framework to identify the role of CFCPs which can help to facilitate externalization activity (e.g. interacting with others' domain knowledge) as well as to increase an individual's internalization activity (e.g. creating personal ideas or reinterpretation of others' ideas). Similar to the structure of the second generation of Activity Theory, CFCPing activity consists of a *subject*, an individual participant who uses prototypes in a design process, the *mediating artifact*, a CFCP, and the *object*, a product idea or solution. Given the increased importance of a cross-functionally organized team structure and user participation in a design process, it is also desirable to combine other components (i.e. rules, a community,

and the division of labor). In this case, the *community* includes all people who are involved in a product development process, such as other specialists on the team, prospective users, and stakeholders. The *rules* can take the form of product regulations, technological constraints, financial limitations, social conventions, company policies, and so on. *Division of labor* refers to efforts that the design team makes through prototypes such as domain-specific knowledge. Figure 4 view the components and their relationships in an early collaborative prototyping situation. Understanding this structure is important because it offers a holistic view of the structure of a CFCPing process, which works as a map for someone who manages the early cross-functional collaboration.

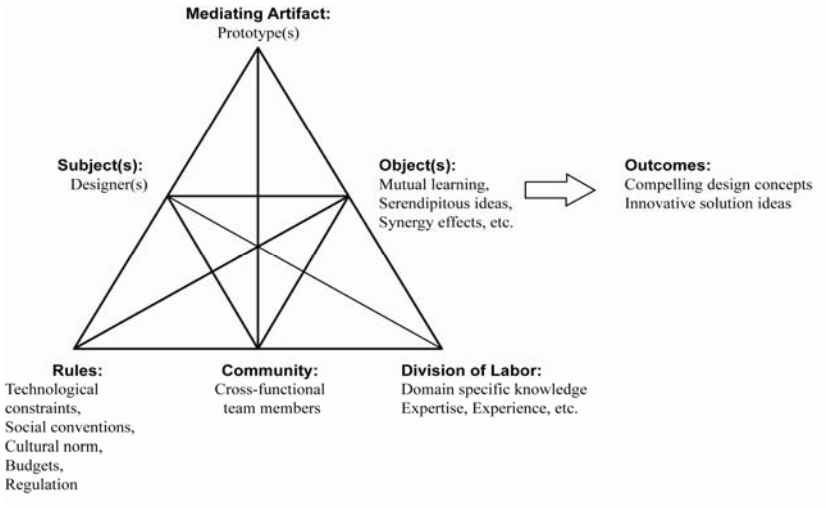

Figure 4. Structure of Cross-functional Collaboration with Prototype as a Mediating Artifact

Another important addition in Engeström's system is the fact that contradictions will occur when those elements interact, but they can work as a driving force to transform the current activity system. By recognizing contradiction, participants can uncover causes of problems, modify mediating artifacts, and reconstruct the rules. By the inherent presence of contradiction in group collaboration, Engeström's recently attempts to extend a single activity system to multiple, interrelated activity systems [11]. As such, the third generation of activity system focuses on cultural diversity and contradictions among multiple activity systems, which is of great importance to the CFCPing process. What matters is the process of reaching a resolution; it is through this process that a CFCP can play a major role as a mediator. For example, when one team presents its first CFCP to other teams in an internal presentation session, the team often encounters contradiction from other team members. In this situation, a CFCP encourages mutual interactions and multiple perspectives, which provide extended collaboration with other teams.

As Engeström [10] insists, "a central challenge for the third generation of activity system is to acquire new ways of working collaboratively", extended collaboration creates more opportunities to increase boundary crossing activities between different teams and new contradictions, which produce a driving factor for mutual learning as well as another design challenge. By extending the scope of the chance for mutual learning from an internal team to an external team, each cross-functional team will achieve more mutual benefits, a major source of creating team's positive momentum. For instance, one group focused more on portability and assembly to

design a product (e.g. a desk, chairs etc.), while another was more concerned about its aesthetics. When these two groups presented their own prototypes, they were surprised to see the difference in their approach to the same product. After sharing their ideas, both teams attempted to compromise on the most suitable solution for their desk design. Figure 5 shows how the third generation of activity theory can be applied to explain the situation.

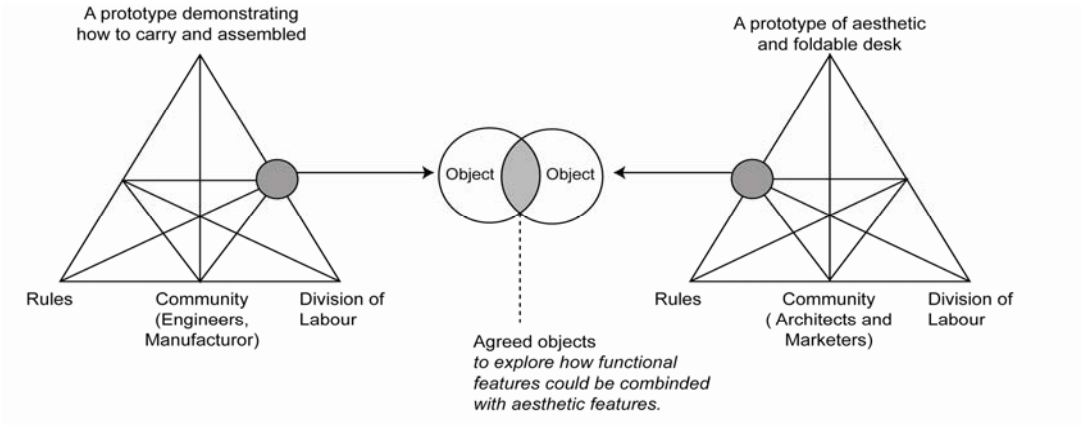

Figure 5. Mutual interaction between different groups in CFCPing Process (adapted from Engeström, 1999)

In summary, Activity Theory provides overall framework of activities in CFCPing process. It emphasizes an individual's internalization process through a mediating artifact as well as externalization process with others. For example, an individually constructed design idea is still in a subjective and implicit state. By using a tool like a pen and paper as a mediating artifact to sketch an idea, individuals can perform "intra-subjective mental actions" [12], which are mostly about personal intuitions, imagination and inspiration. When the individual idea is introduced to the community, people in the community interpret these ideas based on their domain-specific knowledge and experiences as well as social conventions, cultural norms, and technological constraints. In other words, the reinterpretation of given ideas by multiple human agencies can infuse such a diverse perspectives into individual subjective ideas. In this way, subjective ideas have more opportunities to be transformed into collective and objective design concepts. Furthermore, due to the diversity of background and expertise of relevant parties, conflicts between the subject and the community or within the community is certain to arise and CFCPing can play an important role in resolving such conflicts.

5. CFCP as a Design Method

5.1 Prior to a CFCPing Session

Before a CFCPing session begins, CFCPing organizers need to prepare materials that make the session more effective. First, they should recruit cross-functional participants from fields relevant to a design project. Participants do not have to be professionals, but they should have specific domain knowledge and experiences that are closely related to a design project. For example, in developing a new dishwasher, a mechanical engineer and an electronic engineer should be recruited as participants who can give specific domain knowledge as well as chefs, housekeepers, and salespersons who could articulate latent needs, specific problems, and sales points in the market. Next, the organizers need to prepare reference materials relevant to the design challenge and

prototyping materials that support rapid representation of design ideas. Because immediate modification and playful manipulation of ideas are critical factors to conduct an effective CFCPing process, simple and light materials such as paper, duct tape, and modeling clay might be suitable materials. For example, IDEO's initial prototype, out of which IDEO has proudly developed a sinus surgery tool, was a quick prototype made out of materials such as a marker pen, a cloth pin and a film container, which were scattered around the design team (Figure 6).

Figure 6. Early Prototype for the Gyrus ENT Diego at IDEO (Resources from http://labs.ideo.com/about/)

Furthermore, an adequate space has to be secured for a group presentation, a small team discussion, and prototype fabrication. The area should be large enough for all teams to gather for external team presentations but cozy enough for an internal meeting. In addition, the area for fabrication should be provided where a working table and prototyping materials are placed.

5.2 Beginning of a CFCP session

As CFCPing session starts, the organizers need to present the design challenge and describe agenda for the session to all participants. Detailed information about design objectives, a competitive situation, market and technology, financial facts, etc. would help to provide higher level understanding of the contexts of the project. Once the agenda and design challenge are announced, participants should be invited to introduce their background and interest in the design challenge in order to establish a social, professional context. Because participants in CFCPing do not usually know each other well, the initial sharing of each other's professional background and personal motivations will play an important role in establishing effective dialog during a CFCPing session. Furthermore, the three modes of actions (i.e. ideation, embodiments, and critiques) should be introduced as important acts that are expected throughout the entire session.

5.3 Preliminary ideation

After the introduction of design challenge and agenda for the session, participants should be broken into small teams of 3 to 7. Researchers suggest that an inappropriate number of team members may reduce productivity [13]. The observations of CFCPing sessions in this study also suggest that the recommended size is about 3 to 7 people. More team members do not mean better collaboration. What is important is to ensure that each team member has dynamic mutual interactions, so that they can come up with mutual agreements to a solution idea. Once participants are broken into small teams, each team conducts preliminary ideation by capturing different opinions in notes or sketches, which should be organized into like clusters to discuss the nature, opportunity, and challenges. For more effective clustering process, teams should have a central hub that allows people to post the

notes and sketches for sharing. For example, a white board or an easel pad could be set up as the central hub to post different perspectives, opinions, and ideas.

Through conversations, note-taking, diagramming, and sketching, several emergent ideas are discussed. It often shows that verbal conversations about personal experiences, anecdotes, and interesting stories related to the project usually arise first, which in turn creates a warm atmosphere. In addition, physical interactions with an existing product provide an opportunity to find important considerations and insights for the ideation process. After each team generates preliminary ideas, all teams should present their clusters of ideas, discuss pros and cons, and prioritize two or three directions per team in the first group presentation.

5.4 Preliminary prototyping

Based on the prioritized design directions from the first group presentation, each team quickly constructs as many as prototypes possible. In this situation, prototype materials should be simple and flexible enough to allow participants to manipulate alternative ideas at ease. The main purpose of constructing prototypes is to execute implicit thoughts and ideas to be shared with others. The expected actions in this situation are co-construction, negotiation, and discovery of unexpected ideas, among others. Once each team has built several prototypes, all teams should present their prototypes and discuss their pros and cons in the second group presentation. The main goal of this presentation is not to obtain approval from other groups but to discuss each team's ideas. Each group puts their design ideas on the table for physical interaction and cognitive reinterpretation by other groups. Furthermore, it is also a time to shift each group's subjective perspectives on its own design result to more objective points of view.

5.5 Final prototyping

After the second group presentation, all participants are broken into small teams of two in order to construct a prototype in one of the priority directions. In this stage, it is critical to look for opportunities to address challenges and new ideas suggested when prototyping. The prototype helps team members to share their personal thoughts, feelings, and experiences, which generate a reflective discussion between team members. In addition, it is important to keep the deadline for the final prototype. Otherwise, it may take too long, resulting in the prolongation of a CFCPing session. Although the nature and characteristics of the team members should be taken into account, productive team collaboration tends to occur within about 1 or 2 hours maximum. A session of more than 2 hours seems to make participants board and exhausted. However, it is strongly recommended to build an additional prototype after completing one if time allows. At the end of the session, all teams need to get together to present their prototypes to the other groups in the third group presentation and capture the pros and cons of each direction as well as new ideas that develop from the collaborative review.

5.6 Conclusion

Finally, all participants get together as a group to discuss what was accomplished as well as valuable directions, challenges, and benefits realized by working this way. Figure 7 illustrate each stage in detail.

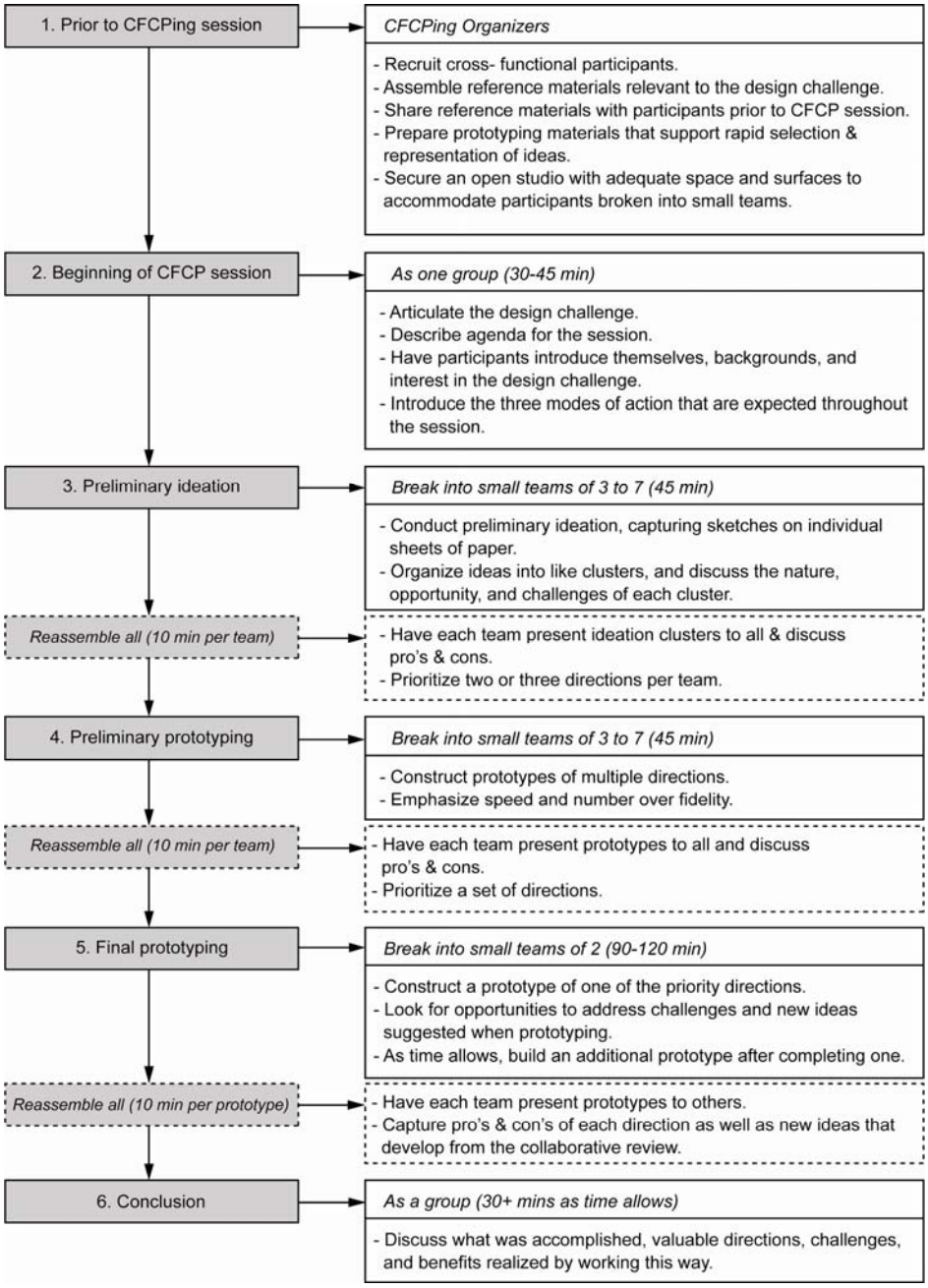

Figure 7. The procedure of CFCPing Method

6. Conclusion and Further study

This study was set out to seek a more complete understanding of the use of prototypes in an early collaborative design situation, particularly in cross-functional collaboration for developing product concept and definition. The insights of CFCP will provide a fuller integration of diverse disciplines' domain-specific knowledge and expertise, helping designers conduct efficient collaboration more easily and thus creating concrete product concepts and definitions more effectively.

For further study, because the types of negative responses given in this paper were somewhat limited, more empirical researches on different types of negative responses from various cross-functional collaborations in design should be conducted. This will provide stronger arguments for the notion of transforming negative effects into a positive driving force. We believe extended research of this study should broaden the boundaries of prototype use in more diverse design projects.

Furthermore, the concepts involved in a CFCP may also contribute to developing a more systematic design curriculum in interdisciplinary departments at the university level and help to develop a new pedagogy for the emerging issues of cross-functional collaboration in design education.

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