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# Fostering engineering students' divergent thinking skill using a collaborative learning environment

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**Abstract:** Design of effective solutions to ill structured problems, is a key skill that engineering students are expected to demonstrate. However students are daunted by the combination of analytical and creative approach required to address a given design problem. Design fixation is a widely prevalent problem seen among students. Emphasis on planning and conceptual design stage involving divergent thinking, is one of the ways to counter design fixation and bring in originality in design solutions. We propose a collaborative learning environment as a means of developing divergent thinking skills among undergraduate engineering students. We use collaboration, shared visual representation, divergent ideation techniques and restructuring thinking patterns as the four main pillars of our divergent thinking learning environment.

**Keywords:** Engineering product design, divergent thinking, collaborative learning environment

## 1. Context and motivation

Engineering design process is complex and includes several activities such as problem scoping, generation of alternate potential solutions, evaluation, selection, and prototyping (Dym et al, 2005). The uncertain, iterative nature of design that calls for decision making at multiple levels, makes it a daunting process to students, hitherto exposed to small structured projects. Consequently, when faced with such an open-ended task, students often look for approximate pre-existing solution ideas that are familiar or appealing and commit to it without exploring solution space, irrespective of the suitability of the solution (Purcell & Gero, 2006). Such fixation often causes students to hit upon snags, which need solution patches, eventually making the solution cumbersome, inelegant and ridden with issues (Ball et al., 1994).

The conceptual design stage is one of the early stages of engineering design process where key decisions regarding the design problem at hand, is taken. The designer abstracts the requirements and searches for suitable solution principles and integrates them into a working structure (Pahl & Beitz, 2013). In this process, various constraints, desired functionality and structure of the solution is considered. Creativity and divergent thinking comes to fore here as the designer does unconstrained searches for alternate ways to solve the given design problem.

At the end of conceptual design stage, the designer has a clear picture of the design requirements and a list of working principles to apply towards solving the design problem. Solution representation in the form of building blocks, schematic diagrams, flow charts, line sketches and rough scale drawings are the key outcome of this stage. The design decisions taken at conceptual design stage have far reaching consequences on the success of the design. Any shortcomings with reference to solution principles not considered at this stage, may prove expensive to correct at the later stages of embodiment design and detail design. It is therefore important to devote considerable chunk of time at conceptual design stage, practice productive divergent thinking and come up with a wide variety of solution alternatives (Cooperrider, 2008). Students predominantly engage in convergent thinking activities (Dym et al, 2005) and are ill equipped to think divergently. Therefore, students require explicit training to think divergently in a given problem context.

## 2. Statement of thesis / problem

The broad research problem we are addressing is, "How to develop divergent thinking skills among undergraduate engineering students in the context of engineering product design"? Eventually we would like to design a learning environment that highlights the importance of divergent thinking in design process and supports development of divergent thinking skill among students. Students have been known to get attached to early solution ideas (fixation) and prematurely skip to detail design (Daly et al, 2012). The feeling of being overwhelmed by design details, insufficiently articulating the scope, constraints and assumptions about the design problem and insufficient knowledge and uncertainty at different levels are key causes of premature closure of solution search. Students therefore require an environment that externally supports them in the cognitively demanding tasks of divergent thinking in design. Such an environment should support (a) exploration of design problem and solution space with multiple perspectives, (b) a visual representation that enables combination and association of diverse ideas and divergent interpretations, (c) divergent thinking facilitation technique (brainstorming) in the context of solving engineering design problem, (d) methods to restructure thinking patterns.

## 3. Features of learning environment

The strategies used to meet the requirements of a learning environment that supports students' divergent thinking process are described below.

1. Collaboration: Collaboration helps widen the problem and solution space due to the multiple perspectives that each collaborator brings (Roschelle, 1992). Successful collaboration helps collaborators build on one-another's ideas.
2. Brainstorming: Brainstorming as a trigger for divergent thinking, has simple rules such as being non-judgmental about ideas, focusing on quantity rather than quality of ideas, and building on others' ideas. It is often used as the first step in collaborative ideation (Rossiter & Lilien, 1994).
3. Concept map as visual representation: In a collaborative ideation process, visual representation of every collaborator's thoughts in a structured form that evolves as the ideas evolve, facilitate easy building of ideas. A concept map like visual representation plays the dual role of reducing cognitive load and making ideas of all collaborators explicit and accessible by structuring, organizing and representing ideas (Stoyanova & Kommers, 2002).
4. Creativity tools for restructuring thinking patterns: Divergent idea generation requires designer to uncover new ways of viewing the problem and solution by intuitive associations and systematic variations (Thompson & Lordan, 1999). Synectics using analogy, check-listing using SCAMPER, and biomimicry are a few ways to stimulate restructuring of ideas.

## 4. Design of solution

Our idea is to build a multi-stage collaborative learning environment as an intervention, to facilitate productive divergent thinking among a group. In developing the learning environment, we operationalized the features such as collaboration, shared visual representation and techniques to aid divergent idea generation. The three stages of the intervention are:

1. Rapid ideation - a time bound activity where participants are mandated with the task of rapidly coming up with ideas for the given engineering design problem. Participants write down the ideas on post-it notes. Idea categories extracted from design literature, scaffold ideation process.
2. Linking - participants link ideas to the core design problem, in a concept-map like form. Participants either randomly pick and link ideas generated during rapid ideation, or generate a fresh idea or connect ideas already present in the concept-map with a link. This stage continues until no new ideas are forthcoming and all ideas from rapid ideation have been used.
3. Conceptual design - participants use ideas from concept-map, and individually come up with two diverse conceptual designs. Participants are instructed to use sketches, block diagrams, or flow charts to represent their conceptual designs.

During the entire process, collaborators do not interact vocally with one another, to ensure free expression of ideas without criticism. Collaboration is restricted to sharing and building on one another's ideas made explicit via post-it notes and the map.

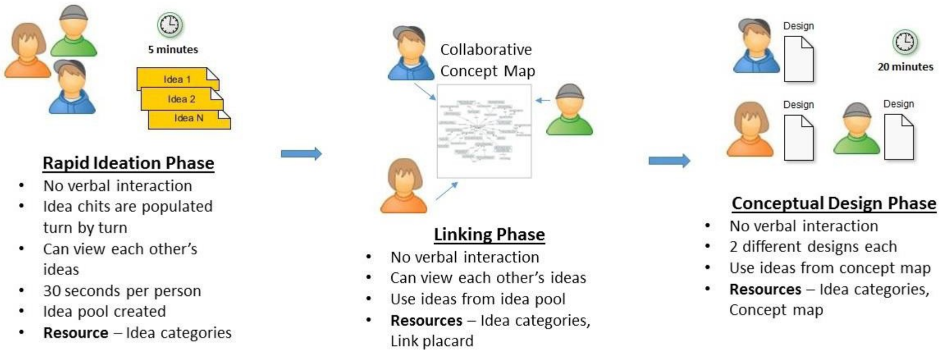


*Figure 1.* The three stages of the collaborative environment

## 5. Research methodology

We plan to use design based research (DBR) methodology proposed by Reeves (Reeves, 2006). There are four stages in DBR cycle. We are iteratively addressing the first two stages of problem analysis and development of solution by referring to relevant work in literature. For the third stage of iterative testing and refinement, we have carried out an initial pilot study. We have so far not addressed the fourth stage of reflection to produce design principles.

## 6. Pilot Study

### *6.1 Research Question*

There are two main research questions that we want to answer with the pilot study.

1. In what ways do the different features of the collaborative learning environment influence the conceptual design of the participants?
2. What is the nature of divergence seen in the alternative designs produced by the students?

### *6.2 Procedure*

- Participants: We conducted the pilot study with four groups comprising of two dyads and two triads, from 3rd and 4th year of their undergraduate engineering course.
- Problem statement: *"Design a shopping cart to be used in a large mall. The cart should be such that it identifies and automatically follows the user. It has space to carry a variety of items. The user can also sit on it and travel around the mall."*
- Materials: Post-it notes, chart paper to draw the concept-map, idea categories card.
- Data sources: Video and audio recording of the concept-map creation, final concept-map, individual conceptual designs, focus group interview.
- Data analysis: We used ethnographic microanalysis of interaction to analyze in detail the multiple audiovisual recordings in conjunction with the focus group interview and final conceptual designs.

### *6.3 Results*

The final conceptual designs were represented in myriad ways such as block diagram, flow charts and prototype sketches. We are still in the process of analyzing the data and student generated artifacts towards answering our research questions. The preliminary results towards answering the first research question about ways in which that the different features of the collaborative learning environment influence the conceptual design of the participants are as below.

- Development of Divergent thinking - Intervention has been successful in elaboration of design. However, despite the availability of collaborators ideas, students found it difficult to come up with two different solutions. Nevertheless, considering the group as a whole, we could observe divergence in the solutions generated.

- Concept-map representation - The concept-map structure encourages students to explore different features of the solution but not radically different solution approaches. The solutions are therefore feature rich but not necessarily diverse.
- Collaboration - In focus group interview, the students claim that the collaboration and concept-map like representation did help them but this help does not seem to translate to output. Very often, students continue with their own train of thought and take very few inputs from the other collaborators.

To answer the second research question regarding the nature of divergence seen in the alternative designs produced by the students, we are in the process of developing an evaluation criteria on how to evaluate designs for divergence. The divergent thinking tests mostly use fluency, flexibility, originality and elaboration as criteria to evaluate divergent thinking (Runco & Acar, 2012). Considering the different forms of representation used in presenting the conceptual designs, we need to evaluate if the above criteria satisfactorily addresses divergent thinking in engineering product design.

## 7. Expected contributions

Our research is focused on improving divergent thinking skills among undergraduate engineering students in the specific context of engineering product design. For a student, the outcome of this research will help by providing a systematic way to employ divergent thinking while participating in the design process. For a teacher, the learning environment can act as the vehicle to encourage students to practice divergent thinking during initial stages of design. For researchers, the outcome of research could contribute towards a formal method of tackling the elusive quality of creativity in engineering design.

## References


Ball, L. J., Evans, J. S. B., & Dennis, I. (1994). Cognitive processes in engineering design: A longitudinal study. *Ergonomics, 37(11)*, 1753-1786.

Cooperrider, B. (2008). The importance of divergent thinking in engineering design. *In Proceedings of the 2008 American Society for Engineering Education Pacific Southwest Annual Conference* (pp. 27-28).

Daly, S. R., Yilmaz, S., Christian, J. L., Seifert, C. M., & Gonzalez, R. (2012). Design heuristics in engineering concept generation. *Journal of Engineering Education, 101(4)*, 601-629.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94(1)*, 103-120.

Pahl, G., & Beitz, W. (2013). Engineering design: a systematic approach. *Springer Science & Business Media*.

Purcell, A. T., Gero, J. S., Edwards, H. M., & Matka, E. (1994). Design fixation and intelligent design aids. *In Artificial Intelligence in Design'94 (pp. 483-495)*. Springer, Dordrecht.

Reeves, T. (2006). Design research from a technology perspective. *In Educational design research (pp. 64-78).* Routledge.

Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *The journal of the learning sciences, 2(3)*, 235-276.

Rossiter, J. R., & Lilien, G. L. (1994). New "brainstorming" principles. *Australian Journal of Management, 19(1),* 61-72.

Runco, M. A., & Acar, S. (2012). Divergent thinking as an indicator of creative potential. *Creativity Research Journal, 24(1)*, 66-75.

Stoyanova, N., & Kommers, P. (2002). Concept mapping as a medium of shared cognition in computer-supported collaborative problem solving. *Journal of Interactive Learning Research, 13(1)*, 111.

Thompson, G., & Lordan, M. (1999). A review of creativity principles applied to engineering design. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 213(1)*, 17-31.