Shih, J. L. et al. (Eds.) (2019). Proceedings of the 27th International Conference on Computers in Education. Taiwan: Asia-Pacific Society for Computers in Education

Flare-Fork: A pedagogy for expanding problem and solution space for design problem solving

Soumya NARAYANAN*, Sahana MURTHY
Indian Institute of Technology Bombay, India
* soumya.n@iitb.ac.in

Abstract: In design, fixation is a recurring problem with novices where they choose the first solution that they think of for a given problem rather than explore a range of possible solutions. Fixation can result in barriers in design process, restricted search and premature commitment to solutions that may be sub-optimal. Among undergraduate engineering students, design fixation is due to limited prior conceptual knowledge, insufficient knowledge of design heuristics, and disconnected and evolving knowledge base, skills and strategies. One mechanism to overcome design fixation is expansion of problem and solution space where learners explore a variety of aspects related to the design problem such as constraints, assumptions, concepts and principles, before deciding on the solution to be followed. To be able to expand problem and solution space, novice designers require support.

We have devised a pedagogical strategy flare-fork which scaffolds students' problem space and solution space expansion in the flare phase and generation of multiple constraint optimized designs in the fork phase. Flare-fork is a systematic process that supports students to build on their opportunistic ideas to expand design boundaries and subsequently identify trade-offs to generate a variety of solutions tailored to fulfill a combination of constraints and assumptions. The pedagogy brings together design strategies, tools and practices such as rapid ideation, shared visual representation, categorization and techniques to restructure thinking patterns in a collaborative environment. In this paper, we first describe the conceptual design of our proposed pedagogy. We then describe a study to examine how the intervention operationalizing the flare phase of the pedagogy supports students in expanding their problem and solution space.

Keywords: Engineering product design, design fixation, expansion of problem-solution space

1. Introduction

Engineering design problems are generally ill structured and complex, making the design activity exploratory in nature. This often leads to designs having emergent characteristics in which the problem and solution co-evolve (Dorst and Cross, 2001). Solutions can vary depending on the initial point of view, the concepts used, the extent of problem explored and the kind of constraints used. While none of the solutions may be wrong, their suitability to the given context may vary.

Students who are novice designers find the unstructured nature of engineering product design quite challenging. They face several design related challenges such as in framing problem, identifying goals, constraints, requirements, making decisions, considering alternatives and switching between different modes of thinking, visualizing and gathering information (Atman et al., 2007). Many novice designers fixate on their first solution idea (depth first approach) and do not make the effort to look for alternate solutions by expanding their problem and solution space (breadth first approach) (Atman et al., 2007). This premature closure on a solution can lead to sub-optimal, pedestrian solutions that can prove intractable at a later stage of design.

One way to prevent premature commitment to a solution is enabling students to expand problem and solution space. The problem space is the task environment of the designer comprising of initial problem state, goals and requirement. The solution space encompasses the possible solutions and the means of evaluating if the solution meets the requirements. During co-evolution, designers iteratively explore the problem requirements and design solutions. In this process new variables emerge in response to changes in each of problem and solution space, which could include new requirements, thereby expanding the initial problem space or new potential solutions which expand the solution space (Hay et al., 2017).

Flare-fork is a pedagogy that we have designed to support and promote expansion of problem and solution space by novice designers while solving an engineering product design problem. The pedagogy combines collaboration, shared visual representation, and strategies to restructure thinking patterns such that students can opportunistically decompose the design problem but still benefit from the subtle structuring introduced by the pedagogy. Flare supports unrestricted search of problem and solution space by facilitating students to think divergently with divergent thinking strategies. Fork supports students in identifying constraints and trade-offs and devising constraint appropriate conceptual designs for the given design problem.

We have developed a collaborative learning environment for the flare phase of the pedagogy. We have used conjecture mapping as a way to articulate how the different components of the intervention viz. the activities, artifacts, resources, scaffolds and the transactions between these components, interact to facilitate problem and solution space expansion. In this paper, we describe an exploratory study as part of the first cycle of design-based research (DBR), where we tested key design and theoretical conjectures that inform the pedagogical support of our collaborative learning environment. The specific research question we are addressing are:

1. How do students explore problem and solution space during design problem solving?
2. In what ways did the different features of the intervention support the expansion of problem and solution space?

2. Theoretical background

2.1 Engineering design

Engineering design is ill structured in nature. During design process, designers structure and frame problem, generate and synthesize solutions, evaluate the alternatives, make decisions towards realizing the project (Atman et al., 2007), (Hay et al., 2017). The elements of design considered include requirements, functionalities, form or structure, behaviour, external environment including stakeholders and constraints (Gero and Kannengiesser, 2004). The complex and ambiguous nature of design can prove difficult for students who then resort to known solutions and pursuing their first idea. This can cause problem of fixation. Fixation has been synonymized with restricted search, satisfaction in search and premature commitment (Crilly and Cardoso, 2017) indicating a restriction of range of ideas that are considered. Fixation occurs when designers unconsciously adhere to prior designs and mimic design features, consciously block generation of new ideas in favour of familiar solution paths (knowledge based fixation), or intentionally resist thinking of new ideas in favour of successful designs (conceptual fixation) (Youmans and Arciszewski, 2014). Fixation can hinder creativity and lead to sub-optimal solutions riddled with problems that require additional fixes. Ways of reducing fixation includes modifying the design environment such that it allows unrestricted consideration of ideas. Group work and rich interactive design environments have been known to lead to original outcomes (Youmans and Arciszewski, 2013).

Designers often undertake wide-ranging exploration of problem and solution space in search of creative solutions. Designers continuously restructure and redefine the problem in their attempt to push the design boundaries. When features and constraints in the solution give rise to new criteria that redefine the problem space there is a response driven modification in each of the design spaces. Expansion of problem and solution space is therefore this incremental extension of problem statements and associated solutions (Maher et al., 1996). Expanding the problem and solution space offers the opportunity to find better designs that have so far not been known to exist. Divergent thinking plays an important role in this idea generation and exploration phase of design (Shah et al., 2012).

2.2 Methods to foster expansion of problem and solution space

Alternative ideas emerge when students think like two different people as in address different perspectives. In this regard, collaboration can prove useful. Collaboration has been known to aid in formation of diverse interpretations. During collaboration, there is a mutual construction of knowledge (Cress et al., 2015) when collaborators grapple with the problem, present alternative perspectives, establish a common frame of reference, negotiate meaning, and restructure ideas. To make the collaborative problem solving process more effective, instructional support in the form of scaffolding is necessary.

Shared representation facilitates access to parts of knowledge of the collaborating group in the form of distributed resources such as a concept map, sketches, and shared worksheets. Shared representation works as a mediating tool with the purpose of engaging and facilitating cognitive processing. Concept maps (CMAP) for instance, helps students to externalize their internal cognitive structure thereby making individual knowledge more explicit. It presents multiple dimensions or perspectives of the picture at once facilitating creative association between ideas via critical reflection and creative thinking among collaborators (Stoyanova and Kommers, 2002).

Divergent idea generation requires designer to uncover new ways of viewing the problem and solution by intuitive associations and systematic variations. Idea stimulating strategies such as adapting, combining, and rearranging, play an important role in imagination by making the manipulation of information more explicit (Eberle, 1972). Such strategies enable designers to span the design space and contemplate employing non-obvious ideas as a solution concept. Additionally, using such strategies help designers to de-fixate from tried and tested solution ideas (Daly et al., 2012). SCAMPER (Eberle, 1972) and design heuristics (Daly et al., 2012) are ways to stimulate restructuring of ideas. Evocative words also have the potential to convey shades of meaning allowing for different interpretations (Lawson and Loke, 1997). Metaphors, synonyms and antonyms (Linsey et al., 2010) can prove to be effective triggers to open up new lines of thought.

3. Flare-Fork pedagogical strategy

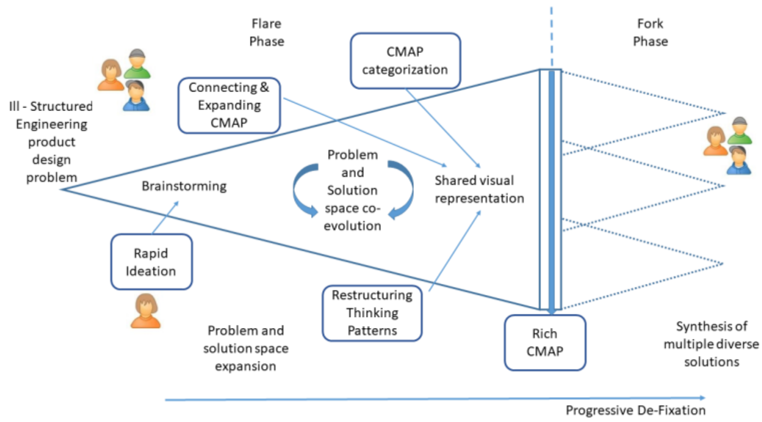

Figure 1. Flare – Fork pedagogical strategy

Flare-fork pedagogy supports novice designers working collaboratively, to build on their opportunistic ideas, expand design boundaries and subsequently identify trade-offs to generate a variety of solutions tailored to fulfill a combination of constraints and assumptions. Flare aspect encourages the designers to progressively expand the problem and solution space by exploring the different aspects of the product design problem at various levels of abstraction in an opportunistic way by brainstorming (non-systematic and multidirectional) (Visser, 2008). A degree of structure is introduced into this opportunistic decomposition (Guindon, 1990) by bringing in the idea of relationship between these sub-systems in the form of concept map (CMAP) creation, followed by categorization. Shared visual representation in the form of collaborative concept map) (Stoyanova and Kommers, 2002) brings semantically and conceptually diverse aspects of the design in one place and facilitates simultaneous consideration of all design parts. This enables the designers to make distant connections, which would otherwise have not been apparent, hidden amidst disparate details.

The intervention successively provides students with means of identifying new search cues for exploring the design problem along new lines. While collaboration helps this by bringing in new perspectives from each of the participant, thought transformer strategies (SCAMPER and SynAnt strategy) provide participants with methods to modify existing ideas to get a fresh perspective. At the end of flare, the designers have a rich, connected and categorized concept map covering several aspects of the product design problem.

Fork aspect of the pedagogy encourages the designers to design alternative solutions for the design problem, considering the conflicting constraints and trade-offs that they can identify. Identifying the conflicts enable designers to view the design problem from multiple levels of abstraction. The conceptual designs so developed is customized for a set of constraints and assumptions. In this paper, we present only the flare intervention design and study its influence in novice design process.

3.1 The flare intervention implementation

The flare intervention begins with a free-wheeling ideation session where the collaborators brainstorm to come up with as many opportunistic ideas regarding the given product design problem, as possible in 5 minutes. This activity is non-collaborative and allows individual designers to produce as many ideas as possible (Stroebe and Diehl, 1994). Idea categories that act as anchor points are used as scaffolds to help trigger thoughts. These anchor points are synthesized from design literature and engineering product specifications. They include functionality, shape/structure (Gero and Kannengiesser, 2004), requirements for working, principle of operation, analogy (Lawson and Loke, 1997), questions (Eris, 2003), and sketches (Lawson and Loke, 1997) as a few exemplar idea categories.

The opportunistic ideas are then connected collaboratively by relating, combining and interlinking them to form a concept map. Addition of new ideas are welcomed so as to make the concept map rich. Scaffolding is provided in the form of SCAMPER (substitute, combine, adjust, modify, put to other uses, eliminate, reverse/rearrange an idea). SCAMPER helps participants transform ideas, change context or perspective thereby triggering imaginative exploration of solution space (Eberle, 1972). Collaborative concept map construction continues until all the ideas from brainstorming are used and no new ideas or links are forthcoming. The collaborative activity is orchestrated by explicit instructions to interact by questioning, explaining, identifying relationship, elaborating and critiquing ideas while constructing the concept map.

SynAnt is a semantic analogy strategy that enables designers to get new search cues for exploring the problem and solution space. Collaborators are prompted to revisit the problem statement, extract key words and search for synonyms and antonyms of these words individually. These synonyms and antonyms (Linsey et al., 2010) are then used to search the World Wide Web for additional inputs informing new ideas. Individual worksheet is provided with task breakdown to orchestrate this activity. Subsequently, participants collaboratively modify the concept map with these new ideas. Towards the end of flare intervention, participants categorize and label the concepts in the concept map. This helps them take stock of the problem and solution space and is an important precursor for consolidation of the ideas in the concept map into conceptual designs. This collaborative activity is orchestrated by explicit instructions to come to a consensus about categorizing concepts in the concept map.

4. Conjecture map

Conjecture mapping is a systematic method to clearly state how the salient features of the learning environment is expected to produce the desired outcomes (Sandoval, 2014). We use conjecture mapping as a means of identifying the pedagogical support for our intervention. Our design and theoretical conjectures were informed from literature on typical processes that guide problem and solution space exploration. Daly et al. (Daly et al., 2014), came up with a rich set of cognitive aspects of creativity that facilitates divergent and convergent thinking towards enhancing creative exploration of the design problem. We used a subset of the cognitive aspects of creativity as the basis for generating design conjectures and theoretical conjectures for our intervention.
Our design conjectures (from Figure 2) are:

1. If learners engage in collaborative CMAP creation with CMAP creation tool, then combining and interlinking of far off ideas will occur.
2. If learners engage in ideation with semantic analogy thought transformer strategy individually then generating new keywords and ideas will occur.
3. If learners engage in collaborative CMAP creation with CMAP creation tool collaboratively, then emergence of partial-solutions from opportunistic ideas will occur.
4. If learners engage in transformation and modification of ideas with SCAMPER thought transformer scaffold individually, then reorganization of ideas by changing context or perspective will occur.

Our theoretical conjecture is: If reorganization of ideas by changing context or perspective, combining and interlinking of far off ideas, emergence of partial-solutions from opportunistic ideas and generation of new keywords and ideas occur, then it will lead to learning to expand problem space and solution space.

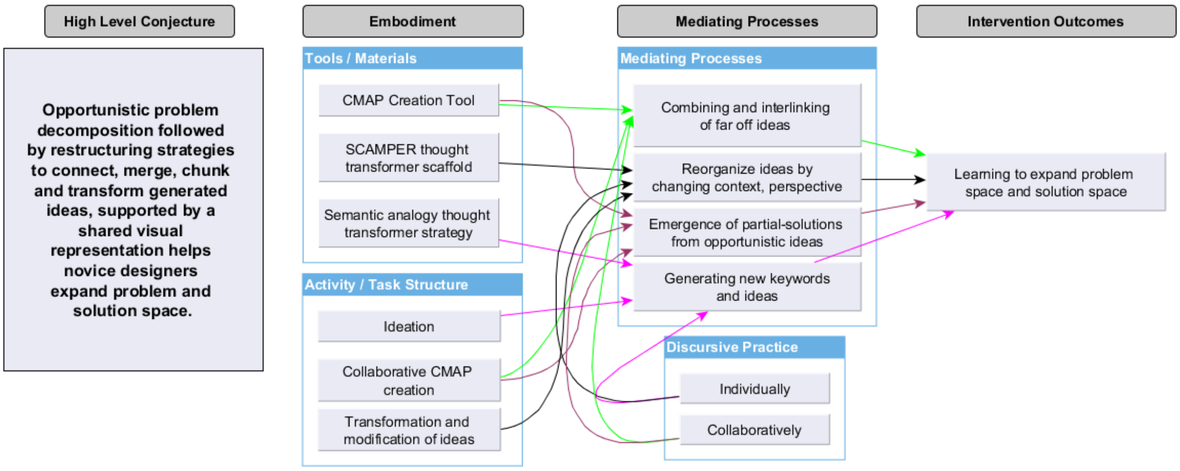

Figure 2. Conjecture map

5. Research Methodology

5.1 Research Questions

The research questions that guide our study are:
1. How do students explore problem and solution space during design problem solving?
2. In what ways did the different features of the intervention support the expansion of problem and solution space?

5.2 Participants

We chose students in their final year undergraduate degree or pursuing their master's degree, as participants for our intervention. At this level, students have already worked on at least one semester long project, but are still not expert designers and are learning new design strategies. Participants were from diverse backgrounds such as computer science, electronics, metallurgical engineering, and chemical engineering. This was based on the idea that teams with diverse background bring in different perspectives to a design problem. We conducted three studies wherein we posed the same engineering design problem to a dyad (group 1) and two triads (group 2 and group 3).

5.3 Procedure

To begin with, we gave the participants the problem of designing a currency cleaner couched as a scenario description. We then outlined the activities, rules and scaffolds in the intervention. We used post-it notes for writing ideas and a chart paper to develop the concept map. We provided a worksheet for SynAnt activity along with access to World Wide Web for focused search.

We video recorded the whole intervention with two video cameras such that one recorder captured the wide-angle view of the actions and behavior of the group while the other camera was a close-up of the map under development. We also audio recorded the whole proceeding. We made regular unstructured observations for recording activities of the participants during the intervention. The audio recording was then transcribed for analysis.

5.4 Data analysis

To investigate how students explore problem and solution space during design problem solving (theoretical conjecture), we used an analytical framework for design process elements and stages framework (Mehalik and Schunn, 2006). The framework is a meta perspective derived from several separate empirical studies on aspects of 'good design'. It identifies 15 elements / stages (summarized in Table 1) of documented observable design process elements that are representative of design activities. The 15 design elements span exploration of problem and solution space. The problem space is the task environment and comprises of initial problem state and problem requirements. The solution space includes the design solutions and foundations for evaluating the requirements (Hay et al., 2016). All possible intermediate states can be considered the bridge (Dorst and Cross, 2001) that identifies problem and solution pair. We used this criteria to categorize the 15 elements into problem space, solution space, intermediate bridge space and others (belonging to stages beyond conceptual design). We chose the unit of analysis to be one conversation turn in the transcription of the three studies. However, to establish context we have referred to sentences immediately before or after the sentence under consideration. We used thematic analysis as a method for identifying, analyzing and reporting patterns corresponding to the codes in our analytical framework, within the data (Braun and Clarke, 2006). Additionally, we analyzed the collaborative concept map generated by students to identify student generated categories and links between and within these categories.

To investigate in what ways the different features of the intervention support expansion of problem and solution space, we used the design conjectures as the analytical framework. The design conjectures are our hypothesis of how our intervention works and by using them as analysis framework, we look for instances that demonstrate the presence of the predicted activity and outcome patterns. We used 5 seconds of video data as the unit of analysis. We localized episodes when students used the particular feature, and scrutinized the video for evidence of productive usage of the feature. We focused on speech, gestures, what was being written and where were the collaborators looking while scrutinizing the video. The above data streams along with the concept map visual artifact provide insights into the view point of each collaborator about the design and ways by which the external visual representation mediated the design process.

Table 1
Common design process elements / stages adapted from (Mehalik and Schunn, 2006)

Category	Definition
Problem representation (EPR)	Framing of a design task including goals, issue, artifact that needs to be analyzed, synthesized, investigated or constructed
Scope of constraints (ESC)	Constraints limit how a design can fulfill goals within problem frame. Designer needs to explore how constraints are affecting the design.
User perspectives (EUP)	Capturing various aspects of requirements, needs of the users.
Evaluate design alternatives (EDA)	Designer's actions to use a framework of performance criteria (goals and constraints) to search and evaluate potential design solutions.
Use functional decomposition (FD)	Breaking down design into several detailed aspects to investigate how the design performs, interacts and contributes to overall functionality
Explore engineering facts (EEF)	Exploring specific knowledge about some property of an aspect of a design. Includes common principles.
Examine existing designs / artifacts (EEDA)	Either look at past designs or existing solution ideas to improve on them in various design dimensions.
Conduct failure analysis (CFA)	Gathering knowledge associated with what produces a failure i.e. when design falls short of goals or performance expectations.
Redefine constraints (RC)	Designer defines a constraint to achieve an original goal.
Validate assumptions and constraints (VAC)	Ensuring that the representation of the user's or other stakeholder's expectations for the design appear to be met.
Graphical representation (EG)	Visualizing details of design to explore overall configuration.
Issues of measurement (EM)	Quantitative information gathering relating to some aspect of design.
Build normative model (BNM)	The ideal, optimal outcomes for the design indicative of designers attempt at formalizing desired outcomes.
Design methodology (FDM)	The documented interactive / recursive / iterative design process.
Reflection on design (ERD)	Designers reflect on their own process that they use to achieve goal.

6. Findings

6.1 Students expansion of problem and solution space

From the graph (Figure 3) depicting group 1 students' design progression with time, we can see that:

- During the design process, student's activities can be mapped to 13 of 15 good design activities.
- Students constantly switch between problem space (green) and solution space (red) with reflection and modification in constraints (brown). This indicates the co-evolution of problem and solution space during design process.

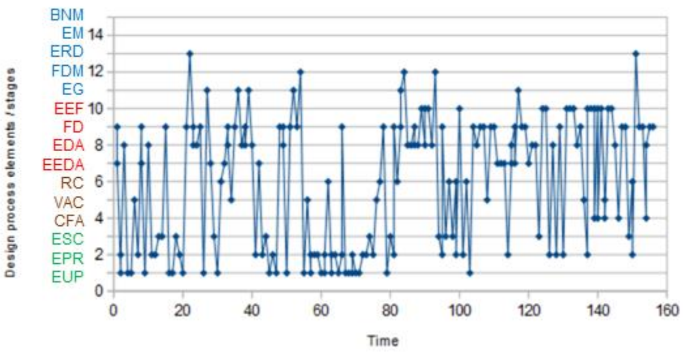

Figure 3. Students design progression depicting exploration of problem and solution space by group 1.

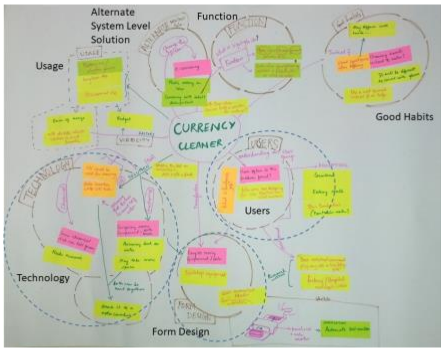

Figure 4. Collaborative concept map generated by group 1 at the end of flare phase

Figure 4 is the expanded problem space and solution space (of group 1) represented as a concept map which is the output of flare of our flare-fork pedagogy. The figure shows student generated categorization and interlinking. The categories that the students identified were usage, good habits, alternate system level solution, function, technology, form design and users. The students connected technology and users to form design thereby forming a relationship between the three disparate categories.

From Figure 5 constructed from an episode in the narrative, we can see how students moved from problem space to solution space, did some analysis on the solution and came up with new constraints and requirements and identified a new problem with a new solution. This episode shows that students expanded problem and solution space during the design process. To summarize, (a) students move back and forth between problem and solution space frequently during the design process, (b) the traversal is via intermediate bridges that link problem and solutions, (c) linking of disparate concepts and categories support the traversal between problem and solution space.

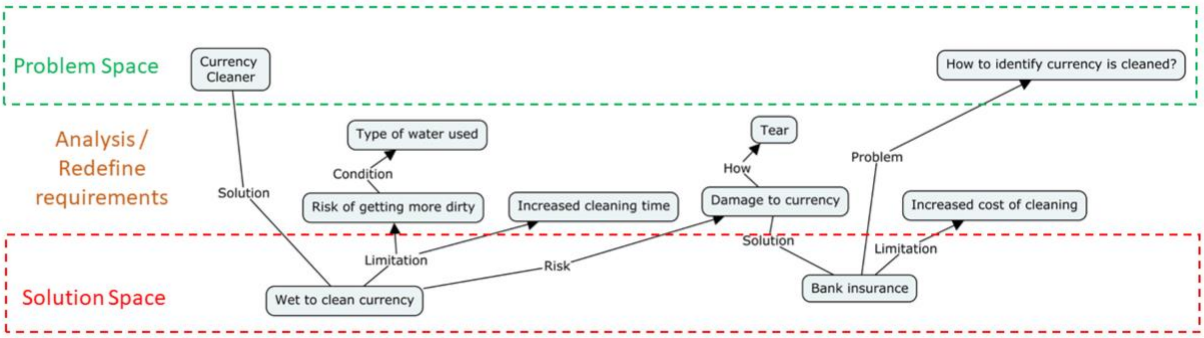

Figure 5. Scenario from narrative depicting expansion of problem and solution space

6.2 Testing design conjectures

6.2.1 Collaborative concept map creation activity promotes interlinking and combination of far off ideas

We found multiple episodes where the collaborators linked different ideas to come up with a new idea. Such links were seen within student identified category as well as across disparate student identified categories. The excerpt extracted from the transcript of group 1, supported by the image sequence in Figure 6 illustrates the linking within and between student generated categories. The hand movements of the collaborators in this excerpt show how the shared external representation mediated the linking of ideas within categories (in this example, under the category of technology solution, linking brush from mechanical domain to UV from electrical domain to form a cleaning mechanism) and linking between categories (in this example category of technology to category of form).

S1 - Or we could combine these two (Points to 'note counter with UV tech' and 'Designing some equipment with brush' as seen from hand movement in frames 1 and 2 of figure 6)
S2 - Ya we can but it would be a bigger equipment (Gesture seen in frame 3 of figure 6)
S1 - But you don't know no, let's see if we come up with something very
S2 - Sleek? (Gesture seen in frame 4 of figure 6)
S1 - It takes care of physical dust particles
S2 - Brush like
S1 - as well as sterilizing it (frame 5 of figure 6)

Figure 6. Image sequence depicting role of shared visual representation (CMAP) during product design

In the above discussion, two diverse aspects of the product viz. the technology to be used and the form factor of the product as identified by the students, is being linked. Observing the gestures during the interaction in the 5 frames of Figure 6, we can see that shared visual representation seems to have facilitated the collaborative linking activity verifying our design conjecture.

6.2.2 Semantic analogy thought transformer usage leads to generating new keywords and ideas

We found episodes where looking at synonyms and antonyms of keywords extracted from the problem, enabled participant to generate new keywords and viewing an idea in a different perspective. An instance of this new perspective is seen in the excerpt below taken from transcript of group 1.

S1: "Currency notes synonyms are cash, roll. So I understood that you know it may not be like my currency is as plain as this. She could be dealing with rolled out or deformed currency also at times so maybe this the form of your input would, just increase the complexity. So again this actually helps in improvising this whole design. What if I just put some money the system could also maybe straighten it up for me and process it? So some adds on straighten up feature".

When the students changed their perspective regarding form of currency, it led to the generation of new requirement - a de-wrinkling system. This new requirement followed by exploration of solutions to satisfy this requirement enabled students to expand problem and solution space. Other instances of productive semantic analogy usage operationalized as SynAnt were (a) 'bleach' as synonym to 'decontaminate' giving rise to bleaching and reprinting clean currency, (b) 'tarnish' as antonym to 'clean' leading to idea of coating currency with protective layer like a 'varnish'. The above instances also indicate flexibility in solution space exploration as a consequence of new keywords triggering reorganization of ideas in new contexts.

6.2.3 Collaborative interlinking of ideas represented in shared concept map facilitates emergence of partial-solutions from opportunistic ideas

Students build on one another's ideas to elaborate the design while engaging in collaborative concept map creation activity. Potential sub-solutions emerge during this elaboration process. In the excerpt below (extracted from transcript of group 1), S1 suggests an opportunistic idea of using a note counting system. We identify this idea as opportunistic because it was not a result of a systematic breakdown of the problem. Rather, S1 used her prior knowledge and fit it into the present design context. S2 recognizes the relevance of this idea to the design problem and links it with technology idea. The shift in focus triggered by S1's opportunistic idea led identification of a requirement and emergence of a partial-solution in the form of using a card reader - note counter kind of system. The expansion of solution space is due to inclusion of similar equipment in search space.

S1: "Can we do something like this note counting thing". (S1 adds the 'note counter with UV tech' idea to the concept map)

S2: "Or you could just put it here and join these two together" (S2 joins idea of 'note counter with UV tech' and 'Designing some equipment with brush' on the concept map)

S2: "So I had seen this card reader. It takes in a card and inside there is an OCR. It reads it and stacks it on one side. So something similar we can have for a note counter, just have to put the note. It cleans with the brush and the UV as well as counts and puts it on the other side".

We could however not find evidence for the final set of design and theoretical conjectures on influence of SCAMPER usage on reorganizing ideas by changing context or perspective, eventually leading to expansion of problem and solution space.

7. Discussion

Our first research question was 'How do students explore problem and solution space during design problem solving'? We found that students frequently move back and forth between problem and solution space during the design process via intermediate bridges that pair problem and solutions. Links within and between categories in the design space support the traversal between problem and solution space. Of the 15 themes from common design process elements / stages (Mehalik and Schunn, 2006), we found that the students' design process covered 13 process elements / stages pertaining to the exploration of problem and solution space. The two themes not addressed were 'exploring issues of measurement' and 'building normative model'. While the issues of measurement become vital in the detailed design, it may play a relatively smaller role in conceptual design stage and assume a ore qualitative form such as speculating if the proposed design alternative would help meet the goal.

The theme related to building normative model implies articulation of ideal outcomes without constraints or limitations by the designers for the given design problem. Since the students followed an opportunistic decomposition path, they predominantly focused on mental simulation of practical scenarios to explore the problem representation and generate solution alternatives. We conjecture that in such context, articulating a normative model would require scaffolding.

The most explored process elements are the exploration of user perspectives, exploration of problem representation and functional decomposition. This is expected as during the initial conceptual design stage, task clarification, requirement understanding, establishing function structures and search for solution concepts and principles sets the solution path and expectations from the design (Pahl and Beitz, 2013). Overall, the intervention seems to support expansion of problem and solution space.

The second research question was 'In what ways did the different features of the intervention support the expansion of problem and solution space'? We found support for three of four design conjectures. This is important because it demonstrates that the intervention in conjunction with orchestration of the whole intervention, support expansion of problem and solution space. There was however a lack of evidence showing that transformation of ideas using SCAMPER thought transformer, influences reorganization of ideas due to changing perspective. We surmise that in the present form, the orchestration of SCAMPER scaffold in the intervention is weak. The usage of SCAMPER thought transformer is kept optional and the mediator occasionally prompts the collaborators to try applying the SCAMPER heuristics to their ideas. We observed that students did not immediately grasp how to implement SCAMPER heuristics to their ideas and asked for examples. This finding aligns with Daly et al (Daly et al., 2012) who commented on the difficulty of applying SCAMPER guidelines. The theoretical conjecture that far off linking can give rise to new constraints and requirements thereby expanding the problem and solution space, could not be verified as the students did not continue investigating this line of thought further.

Going further, we would like to design a more effective orchestration of SCAMPER thought transformer so as to exploit its potential to trigger divergent thinking among students. This is a preliminary study with a small sample size of only three groups and 8 participants, which is a limitation. However the goal of this study is not to generalize, but to understand the role of the various features of the intervention, in order to refine our learning design for fostering problem space and solution space expansion as a means of avoiding design fixation. One of the objectives of this preliminary study was to gain insights about technology support that will inform the design of a CSCL environment. During the study we found that a digital concept map with provision for simultaneous manipulation by collaborators using tangible technologies, can prove to be a valuable support for engaging in co-construction. Integrating private workspace and joint workspace can help collaborators seamlessly switch between them and have smoother collaboration.

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