THE IDEA MAPPING BOARD: A TOOL FOR ASSESSING DESIGN CONCEPTS AND VISUALIZING A TEAM'S USE OF THE DESIGN SPACE

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Abstract

This paper introduces the Idea Mapping Board, a visualization tool that supports the formation of shared mental models within design teams during concept generation and assessment. The Idea Mapping Board is intended for small teams of two to four practicing engineers or engineering students. It incorporates multiple dimensions for concept assessment based on cognitive level and cognitive style. We also present results from two pilot studies used to evaluate the effectiveness and ease of use of the Idea Mapping Board and its impact on the ideation flexibility of its users. This research is part of a larger project funded by the National Science Foundation (NSF) that investigates the impact of multiple factors, methods, and tools on the ideation flexibility of engineering students and practitioners. The Idea Mapping Board was created as part of our investigation of teaming as an intervention to help users expand their exploration of the design space.

Keywords: Teamwork, Evaluation, Visualisation, Design education, Design methods

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1 INTRODUCTION

In team-based ideation and assessment, engineering teams generate an assortment of concepts or solutions in response to a particular design problem or prompt. The outcomes of this concept generation phase are then evaluated in the concept selection phase to determine which ideas are viable based on specified criteria. In some instances, the team members may decide that none of their initial ideas is appropriate for further development and another iteration of concept generation occurs, potentially leading to repeated cycles of concept generation followed by concept selection until the necessary criteria are satisfied. This general iterative process of conception generation paired with concept assessment and selection is widely accepted, but in some settings, it may not have enough structure or incorporate enough reflection to guarantee that design teams fully explore the possible design space.

This paper introduces the Idea Mapping Board, a visualization tool that supports the formation of shared mental models within design teams during concept generation and assessment. The aim of the Idea Mapping Board is to help engineering teams structure their concept generation and assessment in a way that leads to deeper reflection, wider exploration of the design space, and thereby, improved collaboration and design performance. Small teams of two to four individuals (e.g., practicing engineers, engineering students) can use the Idea Mapping Board; it incorporates multiple dimensions for concept assessment based on cognitive level and cognitive style. This paper also presents results from two pilot studies that evaluated the effectiveness and ease of use of the Idea Mapping Board and its impact on the ideation flexibility of its users. This research is part of a larger project funded by the National Science Foundation (NSF) to investigate the impact of multiple factors, methods, and tools on the ideation flexibility of engineering students and practitioners.

2 TEAM-BASED CONCEPT GENERATION AND ASSESSMENT

In engineering practice, some teams evaluate ideas immediately after concept generation using decision matrices or Pugh charts (Pugh 1991). In ideation research, the outcomes of concept generation are often evaluated with metrics like quantity, quality, and variety (Dean et al. 2006, Shah et al. 2003). Being able to assess ideas with reliability and objectivity is critical; having a shared mental model regarding the interpretation of ideas in relation to the problem at hand is an important part of this process. Idea assessment also occurs when individuals evaluate their own ideas. A study on students' perceptions of their own design concepts found that their perceptions of the diversity and creativity of their ideas varied depending on their cognitive style (Jablokow et al. 2015). In particular, students with more structured cognitive styles perceived their design concepts to be more diverse, more creative, but less elaborate when generating solutions in a team, while students with less structured cognitive styles perceived their design concepts to be more elaborate, less diverse, and less creative under the same conditions. These findings pose further questions, including: How accurate are these perceptions and self-assessments? Will teammates perceive and assess ideas in the same manner? Several studies have suggested a difference between perceptions and measures of performance (Paulus et al. 1995, Paulus and Yang 2000). A concern of our work is finding ways to help users assess ideas (both individually and as a team) more effectively and objectively.

Because of the prevalence of teams in engineering design, researchers have investigated the impact of teaming on ideation from many different perspectives. A common approach is to compare the performance of teams and individuals based on the quantity of ideas generated. Results from these studies are mixed; some suggest that teams generate fewer ideas together than the combined results of the same number of individuals working separately (Paulus et al. 1993, Linsey et al. 2010), while other studies suggest that teams generate an equal number of or more ideas (Collins et al. 1964, Linsey et al. 2011). Other researchers use different outcome-based metrics for evaluating the impact of teamwork in concept generation (e.g., the originality, quality, or elaboration of concepts). Diehl et al. (1987) found no significant differences in the originality and feasibility of concepts generated by teams and individuals, respectively, while Helm et al. (2016) found that teams of engineering undergraduates experienced decreases in quantity, clarity, and implicational explicitness and a small increase in idea effectiveness when compared to equivalent numbers of undergraduates working alone. In tandem with performance-based studies, other researchers use behavioral and/or cognitive approaches to investigate less tangible aspects of team-based concept generation, including the formation of shared mental models. Shared mental models refer to common understandings between teammates regarding the

expectations of teamwork, the objectives of the team, the processes used for concept generation, and the interpretation of ideas. Mumford et al. (2001) found that individuals with training in shared mental models were more likely to produce logical and feasible ideas when placed in a team.

One potential issue associated with the formation of shared mental models is the impact of cognitive gaps, which refers to differences in cognitive style (cognitive preference for structure) and cognitive level (mental abilities and subject knowledge) that can exist between people (individuals or teams) and/or between people and the problems they face (Jablokow and Booth 2006, Kirton 2011). A team's particular combination of cognitive styles and cognitive levels may match the requirements of a problem well, for example, but if the resulting style and level gaps between the team members are large, it may limit their ability to work together productively because of conflicting views of the problem and its features (Collins and Guetzkow 1994; Kirton 2011). As Kirton (2011) notes, managing cognitive gaps effectively is important for preventing conflict and leveraging a team's diversity in problem solving; to do so, team members and managers need to be properly equipped with tools and skills that stimulate shared mental models and support clear communication.

The research presented in this paper is part of a larger project in which we are investigating the impact of teaming and other interventions on concept generation in design from both outcome-based and process-based perspectives. In the context of this larger project, we identified the need for a tool to help teams – particularly those that are diverse in terms of cognitive style, cognitive level, and other features (e.g., disciplinary background) – form shared mental models more effectively. In the following sections, we describe the features and use of this new tool (the Idea Mapping Board), along with the results of two pilot tests of its usability with engineering instructors and students.

3 THE IDEA MAPPING BOARD

3.1 Idea Mapping Board Components

The Idea Mapping Board was created primarily as a tool for visualizing a team's use or coverage of the design solution space as they form a shared mental model of the current design problem and the concepts they are generating in response to it. The main component is a rectangular board, as shown in Figure 1.

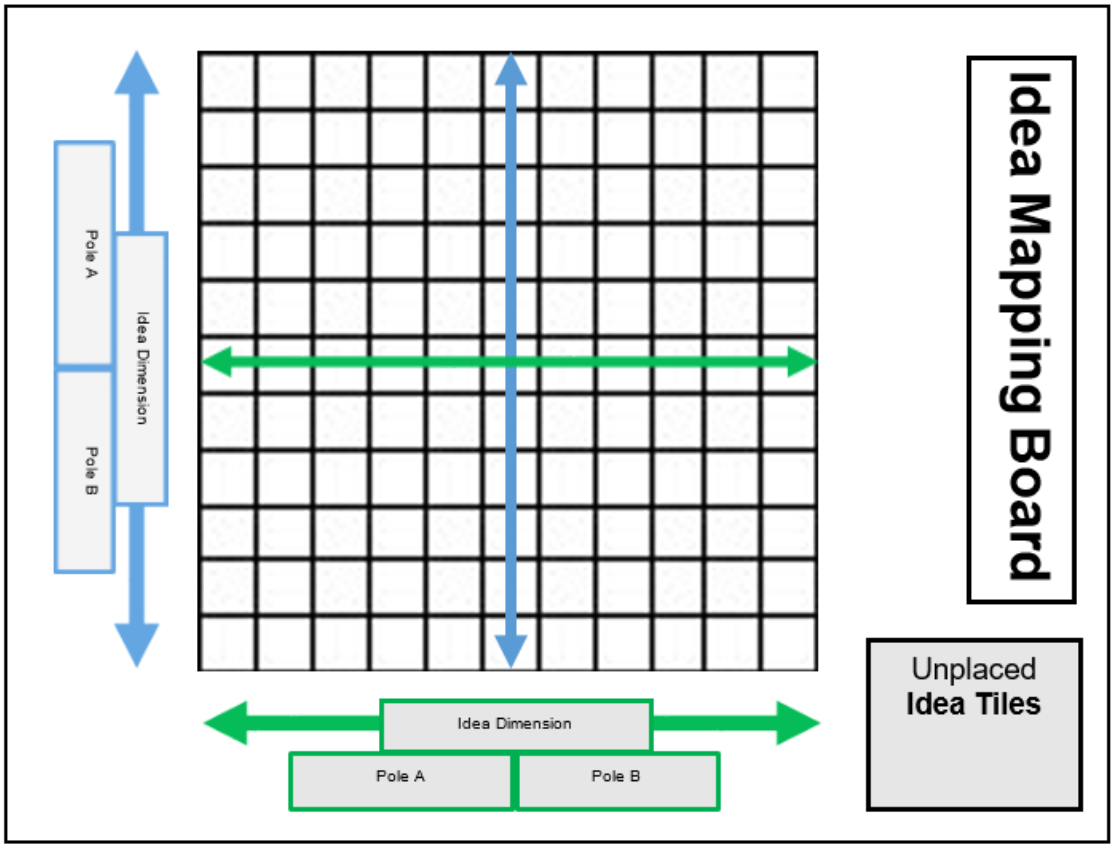

Figure 1. The Idea Mapping Board

The Idea Mapping Board helps users assess the ideas they have generated on a two-dimensional map that represents the design space. The map has eleven rows and eleven columns, with two overlaid arrows that correspond to the two dimensions currently being used to evaluate each idea. The number of rows and the number of columns were selected as a compromise between detail and efficiency. More rows and columns would enable finer distinction between ideas and allow users to be more specific about their idea placement; however, the time spent evaluating each idea is likely to increase in response. Odd numbers of rows and columns were chosen to allow users to more easily identify the "middle" of each dimension. Based on the design and cognitive psychology literature (e.g., Dean et al. 2006, Kirton 2011, Mumford et al. 2001, Shah et al. 2003), we developed two sets of dimensions that represent, respectively, cognitive style features (e.g., idea relevance, originality, conformity) and cognitive level features (e.g., cost, reliability, usability) of a design concept. Users choose two dimensions at a time to evaluate their design concepts and place dimension labels on the board to denote those dimensions. Only two dimensions are selected at a time to reduce the complexity of concept evaluation, making the tool easy to use in practice by both novices and experts. Figure 2 shows two examples of cognitive style dimensions/labels. Descriptions of all dimensions are provided in the Appendix. As shown in Figure 2, each dimension/label has two poles (A and B), which indicate two extrema for that dimension.

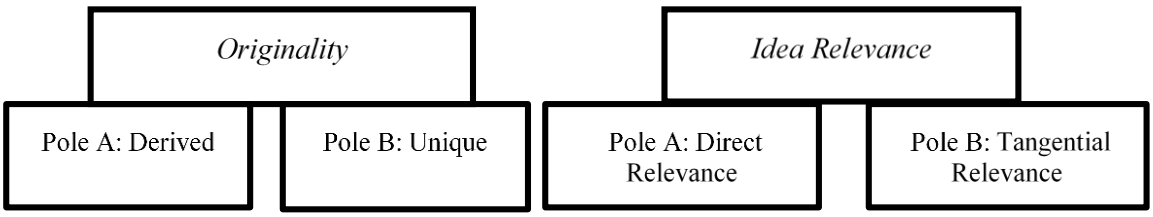

Figure 2. Dimension Labels for Originality and Idea Relevance Dimensions

Users "position" their ideas on the Idea Mapping Board using idea tiles. The tiles are labelled to denote which ideas they represent (Idea 1, Idea 2, etc.); their backgrounds are colored to denote their author and the relevant iteration of concept generation. For example, the idea tiles belonging to one particular user are all blue; the different shades of blue denote the iteration from which that subset of ideas originated. In this way, the Idea Mapping Board supports multiple iterations of concept generation and assessment, allowing users to track the development of their ideas (individually and as a team), as well as their coverage of the design space as they generate more ideas.

3.2 Directions for Using the Idea Mapping Board

Directions for using the Idea Mapping Board consist of three phases: Setup, Idea Assessment, and Discussion (see Table 1). In the Setup phase, users prepare the concepts they have generated previously for mapping on the Board. They also select two dimensions from the set shown in the Appendix to use in assessing their concepts and their coverage of the design solution space. Users may select any two dimensions from this set – i.e., two level dimensions, two style dimensions, or one of each type.

In the Idea Assessment phase, users may individually map all of their ideas onto the Board at once, or they may take turns mapping their ideas one at a time and then shift to a different user. To map a concept on the Board, a user begins by placing the appropriate tile at the center of the Board and explaining the key features of that idea to the rest of their team. Using the two dimensions currently on the Board, the originator of the idea shifts that idea to the location within the design space that he/she believes is most accurate. Once the originator of the concept is finished with his/her explanation, the other team members take turns shifting the concept from its current position (if they feel it is necessary), justifying each movement as they discuss their interpretation of its features. The team must come to consensus on the location of an idea before moving on to the next one; rules for resolving disagreements about a concept's location on the Board are set by the team prior to the mapping process (e.g., the idea originator has the last word or the final position is the "average" of all those suggested).

Finally, in the Discussion phase, the team examines the current mapping of all the concepts and the degree to which the design solution space was explored for the two dimensions used. Based on that discussion, next steps might include generating more ideas to map onto the Board using the same two dimensions or mapping the same set of concepts using a new pair of dimensions. Users might also choose to leave their first iteration of ideas on the Idea Mapping Board and add a new iteration of ideas on top of the previous iteration(s) after additional concept generation. By providing users with defined

dimensions and game-like steps for concept assessment, the Idea Mapping Board provides some basic structure to help scaffold the formation of a team's shared mental model to describe their combined contributions within the design solution space.

Table 1. Directions for Using the Idea Mapping Board

Phase	Directions
Setup	• Place the Idea Mapping Board on a surface that is accessible by all users • Identify/denote generated concepts using idea tiles for each user • Place all assigned idea tiles in the Unplaced Tiles Area • Select two dimensions/labels
Idea Assessment	• Place an idea tile from the Unplaced Tiles Area in the center of the map • Communicate important details regarding the chosen idea to users • Take turns shifting the idea tile and justifying each movement (with one user at a time shifting the idea tile with respect to both dimensions) until a consensus is reached • Evaluate all ideas one at a time
Discussion	• Discuss which parts of design space are most used • Discuss which parts of design space are least used • Discuss similarities and differences between ideas with regard to which idea dimensions are being used • Discuss possible ideas that would incorporate new parts of the design space

4 USER TESTING THE IDEA MAPPING BOARD: TWO PILOT STUDIES

To evaluate the ease of use and effectiveness of the Idea Mapping Board as a concept visualization and assessment tool, two pilot studies were completed. In the first pilot study, we gathered feedback from engineering instructors on the use of the tool; in the second pilot study, we tested an experimental protocol using the Idea Mapping Board with a small group of engineering students. The following basic research questions were formulated to structure these studies:

Ease of use

1. How quickly do users become familiar with the Idea Mapping Board?
2. Which parts of the Idea Mapping Board take more/less time to understand?
3. Are the proposed dimensions understood and interpreted easily?

Effectiveness

4. Does the Idea Mapping Board work for teams with diverse cognitive styles and levels?
5. Does it convey differences between ideas with respect to the dimensions of the design space?
6. Does it provide teams with insights to expand their exploration of the design space?
7. Are the proposed dimensions compatible with each other?

4.1 Pilot Study 1: Gathering Instructor Feedback

Ten engineering instructors of various disciplinary backgrounds participated in a half-day workshop in which the Idea Mapping Board was incorporated. They were asked broad questions regarding the tool after they explored its use through a short brainstorming session in which they generated design ideas individually, followed by an iteration of assessing ideas in teams of two using the tool. Table 2 contains our broad questions and some typical feedback responses. The majority of the feedback regarding the tool's usefulness related to its enabling better visualization of the design space, helping users think critically about the design process, and providing structure for idea assessment. Feedback regarding its challenges pertained mostly to the choice and number of dimensions. Suggestions for improvement were to try larger teams of users and to reduce the number of dimensions from which to choose. Our response to this feedback was to create a well-defined list of descriptions for the dimensions, as shown in the Appendix, so that users can better understand the dimensions and interpret them with greater ease.

Table 2. Workshop Feedback (Engineering Instructors) on Use of the Idea Mapping Board

Question	Feedback
What did you find useful regarding the Idea Mapping Board?	• "exploring empty quadrants is useful" … "useful to see where ideas are in design space" … "visualization of idea groups" • "helps expand design approach" … "taking a step back to assess concept generation process" … "new perspectives" • "provides structure for discussion of ideas" … "can guide development of ideas" • "easy to understand" • "useful for debate with partner"
What challenges did you face in using the Idea Mapping Board?	• "finding empty space" • "how confident are you that you are using the dimensions" … "too many permutations of dimensions" • "it is subjective"
What suggestions do you have for improving the Idea Mapping Board?	• "transfer to larger teams" • "reduce number of dimensions"

4.2 Pilot Study 2: Usability Testing with Engineering Students

A formal 90-minute study investigating the Idea Mapping Board's ease of use and effectiveness was also proposed, as shown in Table 3. To ensure that the proposed study runs smoothly, it was pilot tested with a small group of students to verify that the timing and materials for each of the activities (e.g., scripts, reflection questions) are reasonable, complete, and understandable. Findings of this study will be applicable for users of all types, but the current target audience is engineering undergraduates. The study's main activities include two sessions of individual concept generation and two sessions of idea mapping (i.e., idea assessment) done in teams of two. The purpose of these repeated sessions is to examine how well users are able to expand their exploration of the design space using the Idea Mapping Board in multiple iterations. Expanding their use of the design space is considered a positive outcome, since a greater diversity of ideas provides more options for concept selection and development.

Table 3. Plan for Proposed Research Study

Activity	Description	Duration
Welcome to Idea Generation	Present background info on project and ideation	5
Intro to Concept Generation	Provide instructions and best practices for concept generation	3
Concept Generation 1	Generate ideas for snow transportation problem context individually	8
Reflection 1	Respond to questions regarding creativity, diversity, and elaboration of ideas; difficulty of concept generation	7
Break		5
Intro to Idea Mapping Board	Provide directions for using Idea Mapping Board	3
Idea Mapping 1	Assess ideas in pairs, discuss design space usage, strategize for next iteration of concept generation	8
Reflection 2	Respond to questions regarding creativity, diversity, and elaboration of ideas; difficulty of idea mapping; interpretation of dimensions; design space usage; strategy for next iteration of concept generation	7
Break		5
Concept Generation 2	Same as Concept Generation 1	8
Reflection 3	Same as Reflection 1	7
Break		5
Idea Mapping 2	Same as Idea Mapping 1	8
Reflection 4	Same as Reflection 2	7
Wrap-Up		4

In this study protocol, the first session of concept generation provides a baseline to assess participants' ideation. Sketches and written descriptions of their ideas are collected and assessed using standard performance metrics (e.g., quantity, variety, quality of ideas), while the individual reflection questions provide students' perceptions regarding their own ideas and the difficulty of the initial concept generation. The second session of concept generation and its follow-up reflection are identical, so that the problem statement and context remain the same. The individual reflections on the use of the Idea Mapping Board probe how participants interact with the tool, how their perceptions regarding their ideas change, and how they explore the design space with each iteration.

4.2.1 Research Method

Eight engineering undergraduates participated in a pilot study of the protocol described in Table 3. Participants used the Idea Mapping Board in groups of two to assess design ideas they generated for a design problem focused on new solutions for transporting a person in snow. The methods used for this research, such as the idea sheets, reflections, and the snow transportation problem statement, are based on previous research in ideation flexibility with regard to teamwork, design heuristics, and problem framing in concept generation and are detailed in Jablokow et al. (2015), Yilmaz et al. (2014), and Silk et al. (2014). Originality and idea relevance were used as the dimensions for idea assessment (see Figure 2) in the pilot study. Data collected included sketches and written descriptions of the students' design concepts; photos of the Idea Mapping Board for each team; and feedback based on the same survey questions we used with engineering instructors (see Table 4), as well as additional questions focused on types of ideas and design space visualization (see Table 5).

4.2.2 Results and Discussion

Student feedback (as summarized in Tables 4 and 5) showed that the Idea Mapping Board is effective as a visualization tool, but with room for improvement. In terms of its usefulness, challenges, and their suggestions for improvement (see Table 4), the students' responses aligned well with the instructor responses from the earlier workshop (see Table 2). The students also found the tool useful for visualizing ideas, assessing ideas, and understanding how the design space was explored (see Table 5). For challenges, the students reported that using the dimensions was not straightforward. Their responses suggest that using the dimensions may be more complex than we had anticipated; specific features of an idea must first be selected for evaluation and communicated with regard to a given dimension. Placement of an idea is then relative to the two poles for that dimension, which students found difficult without a specific "grading" scale or other formal criteria.

Table 4. Pilot Study Feedback (Engineering Students) on Use of the Idea Mapping Board

Question	Feedback
What did you find *useful* regarding the Idea Mapping Board?	• "visualizing how ideas compare" … "easier to visualize where ideas stand" … "see how design space is covered" • "able to get feedback" … "get to see if idea is applicable to situation" … "helped for grading my ideas" • "able to observe my tendencies when I design" … "found my ideas were more relevant than I thought"
What *challenges* did you face in using the Idea Mapping Board?	• "sometimes conveying idea was difficult" … "relevance seemed most difficult to place (questions of which aspect of design to focus)" … "not a clear representation of where something stands" • "not knowing how far to go" … "not know how in depth to go" … "needed grading scale with criteria" • "timing is hard" … "discussions could have continued longer"
What *suggestions* do you have for improving the Idea Mapping Board?	• "more time dedicated to mapping and discussion" • "more factors played a role, like cost" … "need more factors at once" • "use more relevant grading scales" … "grading scale so everyone knows what it's being compared to" • "increase size of grid" … "bigger board"

Table 5. Pilot Study Feedback (Engineering Students) with regard to Types of Ideas and Visualization

Question	Feedback
What types of ideas were *easiest to evaluate* using the Idea Mapping Board?	• "ideas already existing" • "effective ideas" … "ideas directly addressing the problem at hand" … "ideas that were relevant and derived" • "my ideas were easiest to evaluate because I know details of my ideas"
Were you better able to *visualize the design space* using the Idea Mapping Board?	• "helped visually see where ideas are in terms of originality and relevance" … "using idea mapping helped because it gave us a rubric to score" … "I become more aware of possibilities of ideas in this design space by having it on board" • "broader view" • "helped distinguish between good and bad ideas" … "talking about unfilled quadrants was useful"

The other notable student feedback was that the idea assessment activities required more time than we anticipated; most students reported that they were unable to evaluate all of their team's ideas in the time allotted. The participants were also instructed to discuss their use of the design space during the same activity, so this cutoff is a concern when trying to judge the tool's usefulness for discussion. On average, the students produced two to three ideas during concept generation, so teams were expected to assess four to six ideas in less than eight minutes. In future full studies using this protocol, more time will be allotted for discussion and mapping of the concepts. The particular dimensions used in this pilot study (originality and idea relevance) may have introduced another issue in assessing the Idea Mapping Board. Using these two dimensions, most of the student teams created similar patterns on their maps, even though their concepts were quite varied. In Figure 3, one team's map is presented with the concepts of different participants marked by color. In this example, the team assessed almost all of their ideas as directly relevant, while they differed more markedly in terms of originality.

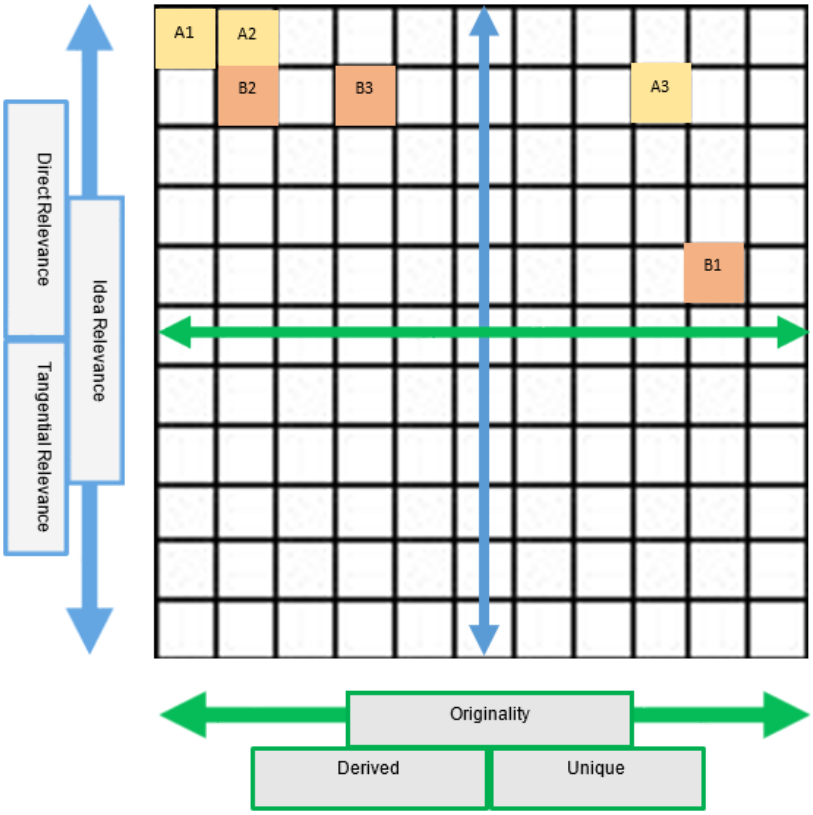

Figure 3. Example of Idea Mapping Board

Maps from other teams shared this pattern – i.e., their ideas showed little variation in terms of relevance, while concepts originality varied more. This lack of variation in idea relevance between groups could be problematic, so idea relevance may not be the best dimension for use in future studies, or the definition of the dimension may require further thought. Another reason to question using idea relevance for future testing is a contradiction with regard to diversity. The participants are told that the purpose of the Idea Mapping Board is to help them visualize and be more diverse in the design space for one given problem context. However, if participants are instructed in each iteration to seek new kinds of ideas, such as ideas with tangential relevance, then they may not be motivated to generate ideas for the problem context.

5 CONCLUSIONS AND FUTURE WORK

In this work, the Idea Mapping Board was introduced and evaluated through two case studies with regard to its ease of use and effectiveness in assessing design concepts and in visualizing the combined use of the design space by team members. Preliminary results suggest that both engineering practitioners and students are able to understand and use the tool for design space visualization; however, there are also challenges with the proposed dimensions of assessment and their interpretation. User responses suggest that the Idea Mapping Board may be more useful than other tools because of its emphasis on visualization. This visualization is helpful for comparing ideas and viewing the design space; however, more investigation will be needed to benchmark this tool in depth against other idea evaluation and concept generation tools. In future work, the experimental study will be extended to allow larger numbers of participants to utilize the tool more fully; the idea mapping activity will also be split into two activities, so that idea assessment and discussion are each allotted more time. Future research will also examine the proposed dimensions, their compatibility with one another, and their effectiveness in ideation flexibility research in general.

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APPENDIX

Table 6. Proposed Level Dimensions for Idea Mapping Board

Level Dimensions	Pole A	Pole B
Cost: What price or resources are exhausted?	*Inexpensive*: Low price/few resources spent	*Expensive*: High price/many resources spent
Number of Components: How many unique components are present?	*Few Components*: Idea has few components	*Many Components*: Idea has many components
Accuracy: Are outcomes within tolerances?	*Close to Reference*: Small tolerance/error	*Far from Reference*: Large tolerance/error
Precision: Are repeated results close?	*Very Precise*: Results have low variance	*Imprecise*: Results have high variance
Re-Usability: What is its lifespan?	*One-Time Use*: Idea works once	*Infinite Uses*: Idea works again and again

Table 7. Proposed Style Dimensions for Idea Mapping Board

Style Dimensions	Pole A	Pole B
Conformity: How does the idea conform to expected norms?	*Conformist*: Idea conforms to norms and standards	*Non-Conformist*: Idea does not conform to norms and standards
Social Acceptability: Is society willing to accept this idea?	*Allowable*: Idea is acceptable from social perspectives	*Taboo*: Idea would never be permitted for social reasons
Change: What kind of impact does the idea have?	*Incremental*: Idea introduced changes that refine and polish	*Radical*: Idea introduces changes that reframe or replace
Originality: How original is the idea?	*Derived*: Idea has clear predecessors and connections to existing ideas.	*Unique*: Idea has no clear predecessors and cannot be related to existing ideas
Idea Relevance: How does the idea relate to the stated problem?	*Direct Relevance*: Idea is clearly relevant	*Tangential Relevance*: Idea relevance is less obvious