AC 2011-1356: AN INVESTIGATION ON THE IMPACT OF THE DESIGN PROBLEM IN IDEATION EFFECTIVENESS RESEARCH

Gul E. Okudan Kremer, Pennsylvania State University, University Park

Gul Kremer is an Associate Professor of Engineering Design and Industrial Engineering at the Pennsylvania State University. She received her Ph.D. from University of Missouri-Rolla in Engineering Management and Systems Engineering. Her research interests include multi-criteria decision analysis methods applied to improvement of products and systems and enhancing creativity in engineering design settings. Her published work appears in journals such as Journal of Mechanical Design, Journal of Engineering Design, Journal of Intelligent Manufacturing, Journal of Engineering Education, European Journal of Engineering Education and Technovation. She is a member of IIE, ASME, and ASEE. She is also a National Research Council-US AFRL Summer Faculty Fellow for the Human Effectiveness Directorate (2002-2004), an invited participant of the National Academy of Engineering (NAE) Frontiers in Engineering Education Symposium (2009), and a Fulbright Scholar to Ireland (2010).

Linda C. Schmidt, University of Maryland, College Park

Linda C. Schmidt is an Associate Professor in the Department of Mechanical Engineering at the University of Maryland. Dr. Schmidt's research interests are in understanding the process by which early stage, engineering design tasks are successfully completed so that we can devise effective methods for learning design and preserving knowledge that arises in the process. She has been actively teaching and reflecting upon engineering design issues for over 15 years. Dr. Schmidt was the 2008 recipient of the American Society of Engineering Education's prestigious Fred Merryfield Design Award and is the co-author with George Dieter of the text "Engineering Design, 4th edition", published by McGraw Hill in 2008. Linda Schmidt has published over sixty refereed publications in the areas of mechanical design theory and methodology, mechanism design generation, graph isomorphism issues in generative design and effective student learning on engineering project design teams.

Noe Vargas Hernandez, University of Texas at El Paso

Dr. Vargas Hernandez research focuses on engineering design creativity, ideation metrics, design innovation, ideation methods, cognitive psychology, TRIZ, use of smartpen, design education, computer aided conceptual design, design of neuromusculoskeletal rehabilitation devices and design for sustainability.

An Investigation on the Impact of the Design Problem in Ideation Effectiveness Research

Introduction

While the quality of the undergraduate engineering programs has been monitored through several means (e.g., ABET) in the US and in international locations, in the face of grand challenges for engineering[1], many efforts have been undertaken to create the vision for what we should expect from our undergraduate engineering students, and how we should help them live up to these expectations. For example, one of the significant reports[2] discussing these issues indicates that our graduates should aspire "*to have the ingenuity of Lillian Gilbreth, the problem-solving capabilities of Gordon Moore, the scientific insight of Albert Einstein, the creativity of Pablo Picasso, the determination of the Wright brothers, the leadership abilities of Bill Gates, the conscience of Eleanor Roosevelt, the vision of Martin Luther King, and the curiosity and wonder of our grandchildren.*" This statement implies that not only should our graduates be very well equipped with analytical skills but also master creative problem solving. Indeed, given the projections[2] that (1) the pace of technological innovation will continue to be rapid, (2) the world in which technology will be deployed will be intensely globally interconnected, and (3) designers, manufacturers, distributors, users will be increasingly diverse and multidisciplinary; our graduates will need to develop these skills to a higher degree.

Despite this need, however, the engineering education has been observed to do the opposite, at least on enhancing creative problem solving skills. For example, students who need more creative outlets have been observed to leave engineering programs[3], or engineering student creativity has been traced to decline[4]. Given this situation, several efforts have been undertaken to stop and reverse this trend. One of these efforts is infusing engineering curriculum with systematic problem solving methods (TRIZ) and aiding design cognition and creativity through design capture using manual or digital means (sketching), and subsequently analyzing the effectiveness of introduced methods/tools in comparison to control groups. In general, such experimentations are done in engineering design settings (e.g., first year design, capstone design, etc.).

In ideation effectiveness research settings, the design problem engineering students are facing could present a biasing factor. For example, the theme and or the context of the design problem may or may not be familiar to the student (potentially impacting student's ability to use relevant terminology and relating existing knowledge), or the goal of the design problem may or may not be acceptable to the student which in turn might influence the motivation (e.g., humanitarian design projects versus others). In this paper, we explore the potential dimensions of the design problems that could constitute biasing factors in design settings. Below, we first summarize the existing research we draw from, and outline factors that should be taken into account during ideation focused classroom experiments.

Literature Review

Based on our collective prior knowledge on design theory as well as our experience in teaching engineering, we assert that structuredness, situatedness (context specificity), the level of ambiguity, gender orientation, and finally the complexity of the problem might impact the performance of the human subjects in design settings. We present the relevant literature below after a brief discussion on our understanding of design problem solving.

Our frame of reference on design problem solving

In the engineering practice, problem solving often is done in the context of designing a product, a system, or a process. The engineering design process is central to the practice of engineering, and as such in the U.S. most engineering programs made a commitment to teach design. This commitment necessitated a better understanding on what design is. Now, there exists a consensus around a new set of ideas that are closely related to the process of product design and development employed by industry[5], and in fact, the ABET definition of engineering design reflects this consensus: "[Engineering design is] the process of devising a system, component, or process to meet desired needs."[6] Further, ABET requirements for accreditation of engineering programs state that a curriculum must include the following:

- development of student creativity through open-ended problems;
- use of modern design theory and methodology;
- formulation of design problem statements and specifications;
- consideration of alternative solutions and their feasibility considerations;
- production processes and detailed system descriptions; and
- concurrent engineering design.

ABET also indicates that the design experience should[5, 6]:

- include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact;
- be a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills;
- be taught in section sizes that are small enough to allow interaction between teacher and student;
- be an experience that must grow with the student's development; and
- focus the student's attention on professional practice and be drawn from past course work.

There exist various models of the design process[7]; however, most steps in these process models are similar. For example, all design efforts involve evaluation of alternative solutions. ABET states that "among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation."[6] We also note that these phases have been referred to in similar but different ways in the literature across various engineering design texts (See the comparisons of engineering design processes across textbooks in Ogot and Kremer[8]). To provide a reference point, the engineering design process may be thought of as having roughly four phases[5], although it is important to acknowledge that the design process is iterative. These four phases are: (1) needs assessment and defining the problem; (2) generating concepts or solutions; (3) evaluating, and selecting a concept; and (4) implementing and communicating the design.

Despite the above mentioned consensus, however, due to the changing application foci across different engineering disciplines, the level of emphasis placed on certain design skills varies. For example, while mechanical and bioengineering disciplines focus more on the products, in general, industrial and chemical engineers would focus on systems and processes. Accordingly, the tools (approaches) with which designs are completed might differ, such as chemical engineers and industrial engineers use computer simulations to a higher degree, while mechanical engineering students are expected to build prototypes.

Structuredness & Situatedness

Although, we have stated that in the engineering domain, problem solving is mostly experienced as design problems, we nevertheless opt to present prominent distinctions between problem solving and design, which may help explain the impact of structuredness. In its most generic form, problem solving is defined as "…find[ing] a path through the problem space that starts with initial states passing along paths that satisfy the path constraints and ends in the goal state[9]. The ***level of structure*** in a given problem (or its structuredness) and its situatedness are two important dimensions describing the type of problems. Well-structured problems are those that are encountered in educational settings – the textbook problems, and have "all the information needed to solve the problems in the problem representation; they require the application of a limited number of …rules and principles that are organized in a predictive and prescriptive way; and they have knowable, comprehensible solutions where the relations between decision choices and all problem states are known or probabilistic[9]. On the other hand, ill-structured problems are interdisciplinary in nature, with conflicting goals and multiple solution methods. Jonassen[9] argues that ***structuredness*** also relates to ***situatedness*** – that is, the more structured the problem is the less context-specific the problem becomes. Typical engineering problems, which are mostly design problems, are classified as ill-structured and situated (context-specific) problems. Indeed, Jonassen[9] refers to a design problem as "perhaps the most ill-structured kind of problem".

Supporting the theoretical descriptions above, empirical studies of problem solving in design problem spaces versus non-design problem spaces showed clear differences how subjects approached problem solving. For example, Goel[10] found that design problems required: 1) incremental development of an artifact (that is designed), 2) problem structuring with relatively large percentage of time devoted to it (25%), and 3) existence of several problem solving phases: preliminary design, refinement (design iteration); whereas none of these were applicable in non-design problem spaces.

Ambiguity & Gender Orientation

Ambiguity refers to perceived information insufficiency and is used to describe decisions for which the odds of an uncertain event are not precisely known[11]. Although much has been written regarding making decisions under conditions of ambiguity or uncertainty, and models have been proposed to describe this process (e.g., Einhorn and Hogarth[12]); the implications for the design setting have only been sparsely studied[13]. In addition to the level of ambiguity inherent in a task or project, individuals can be categorized as ambiguity averse, ambiguity seeking, or ambiguity indifferent[12]. Tolerance for ambiguity is a personality variable defined as the tendency to perceive ambiguous situations as desirable[14]. Need for closure is a related construct referring to a desire for definitive knowledge, for a firm answer to a question and an aversion to ambiguity[15].

Design tasks or problems will differ with regard to their level of abstractness and ambiguity, and design subjects might display varying degrees of readiness to deal with open-ended problem solving. The fact that ABET requires inclusion of open-ended design problems in the curriculum necessitates that students experience such problem solving settings. However, insufficient attention has been given to these issues in the literature, despite their potential importance for building self-efficacy as well as increased student learning and performance. In experimental settings, due to their potential impact on student performance (i.e., designed artifact, or design solutions) perceived ambiguity level of a design task and the tolerance for ambiguity level of experiment participants (subjects) should be taken into account during the analysis of results.

A relevant construct to ambiguity might be the gender orientation of a design task as certain tasks can be more oriented towards one gender, and perhaps less ambiguous. Research has shown that occupations are perceived to have a ***gender orientation***. For example, Shinar[16] and a later replication by Beggs and Doolittle[17] revealed that engineering is generally perceived as a masculine occupation. Not only is the engineering field perceived to have a gender orientation, but the specific design domain in which individuals perform tasks may also be perceived by team members to be more masculine or feminine. Although the process of designing (e.g., generating alternatives, evaluating the final design) would not have a gender orientation, the domain of the task may accentuate gender differences in team functioning.

A literature search revealed that little research has examined task gender orientation. For example, most gender composition studies have not included this variable, although the results discussed above indicate that it may be relevant (e.g., Harrison et al.[18], Randel[19], Laeser et al.[20]). In addition, the research that has been done may be improved upon by giving more systematic attention to the measurement of gender orientation of the project domain.

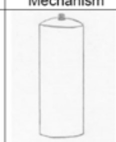
For example, some authors have simply suggested that tasks may be more masculine or feminine without directly measuring the variable to provide empirical support (e.g., Wood[21]). Others have examined the dimension in a cursory and indirect manner. For example, LePine et al.[22] utilized a simulation of a military task for command and control teams, which was assumed to be masculine, but the gender orientation was not directly assessed or validated. Studies that have directly measured gender orientation have typically selected stereotypically sex-typed tasks based on previous work on gender differences and then validated those assessments on a pre-test sample. To illustrate, tasks based on sports, changing oil, and designing a tool shed were rated to be more masculine, whereas tasks based on flowers, cooking a meal, and designing a store window were rated to be more feminine[23]. In addition, Wentworth and Anderson[24] utilized pre-tested masculine (investment decisions), feminine (wedding planning), and gender-neutral tasks (advising a married couple on how to spend an inheritance).

Given the discussion above, it is clear that design tasks can be perceived to have a gender orientation, and this orientation might impact the performance of the participants in design settings. Accordingly, we argue that to arrive at design performance analysis that is unbiased, the gender orientation of the product design task should be taken into account.

Complexity

Some other noticeable characteristic of design tasks is their complexity. This characteristic is focused in the amount of work and time required to accomplish the task[25, 26]. Some ideation tasks might be harder to solve even though they are applied to the correct domain, where the solution requires a great effort to bear or they can be relatively simple to solve[27, 28]. Also, a problem might be constructed of many parts or it can be fairly simple, involving just a single part[28, 29]. The perceived complexity of the problem perhaps can be traced by how the designer represents the design domain using morphological charts. The following table shows a morphological chart prepared by a design team focusing on a coffee maker re-design. For example, an increase in the number of potential solution clusters (shown as separate columns in the table) might indicate the extent of the attention given to different facets of the design problem, and how the designer perceives the overall structure of the problem. We note, however, different facets of focus presented in a morphological chart can be predominantly relevant to form, function, or both. For example, in Table 1, under the column heading "coffee pots", we observe various designs which are different in shape. Designs under "heating mechanism" and "reheating mechanism" are more relevant to a function, which might require a greater focus on potential technology options. In general, designs for which function is focused on to a higher extent can be seen to be more complex.

Table 1. A Sample Morphological Chart

Means	Function				
	Coffee Pots	Heating Mechanism	Display	Materials	Reheating Mechanism
1	 Stainless Steel with insulating interior	 Propane in small canister	An analogue display involving a clock with hands	Stainless steel with some kind of heat resistant plastic	 Contacts at the top conduct current to pot
2	 Glass with plastic handle	 Pre-boiled water	A digital display powered by LEDs	Black or white plastic/ composite	Heat comes from a place on which the pot is placed
3	 Tall and slim	Conventional coil which heat the water as it runs through the machine	An interactive touchscreen display	Bamboo	 Both side and bottom provide heat
4	 Handle dug out of body		No display/ On-Off Switch	Teflon (interior)	

Preliminary Results

We use data from our ongoing research (NSF CCLI 0920446) to compare the differences across the ideation tasks for which we measure the design artifact's creativity using quantitative means (quantity, novelty, and variety). Thus far we have included the following ideation tasks in classroom experimentations, and collected ideation effectiveness data. Our goal with the work presented here is to further qualify the differences across projects, which will enable comparisons across the whole data set.

1. Many outdoors sports played on natural grass require lines be drawn to indicate boundaries and other field markings. Conventionally, such lines are marked by chalk or paint to create the line on the grass. The drawback with these techniques is that the line markings are temporary and must be reapplied from time to time. Also, contestants may run over the lines and obliterate them during the game. Alternatively, the lines may be created by using

diesel or other chemicals to kill the grass, a process that has become environmentally unacceptable. Develop several concepts to replace the drawn lines. (Design task taken from Ogot and Kremer[8].)

2. A number of devices have been patented to accomplish the task of removing the cork from a champagne bottle. Most of them attempt to pry or pull the stopper out by exerting a force between the top of the bottle and the enlarged, exposed part of the cork. Champagne corks are tightest before the initial displacement, which breaks the bond to the bottle created over weeks or months of storage. Teeth forced into the uncompressed cork can tear or fracture the cap, leaving even less to work with. Develop several concepts to open a corked bottle. (Design task taken from Ogot and Kremer[8].)

3. Commercial cooking ovens are designed to cook food quickly and efficiently. The heat they generate, however, causes the exterior to become very hot, posing a hazard to both employees and adjacent equipment. In addition, the heat radiated from the exterior raises the ambient temperature of the kitchen resulting in higher energy costs through wasted heat and increased air conditioning. Develop several concepts for a better cooking system. (Design task taken from Ogot and Kremer[8].)

4. In rural areas of developing countries, such as Kenya, cooking is done in the home with biomass type cooking systems. One of the adverse affects of these cooking systems is the emissions which cause respiratory illnesses for millions of children and women. The people in these developing countries are economically and culturally constrained by the types of cooking systems they use. Also, depending on the type of biomass used there can be unsustainable and detrimental effects on the environment. Develop several concepts for a cooking system that is culturally appropriate, sustainable and low cost to meet the needs of rural Kenya.

5. As identified in "Energy-Efficient Traffic Lights Can't Melt Snow" by Dinesh Ramde, while LED bulbs provides energy savings when used in traffic lights, in cold climates because the ambient heat generated by the bulb is low, the traffic light remains snow covered, and cannot function to safely direct traffic. Develop several concepts to solve this problem. (Design task developed for NSF CCLI 0920446 project activities.)

These design tasks involve features that will enable studying the above mentioned potential constructs for their bias in design settings. For example, playing field sports might be more oriented to male subjects, while cooking to females. Cooking in rural settings will be somewhat ambiguous to city dwellers.

To complement our assertions on the biasing factors based on our review of the literature, using a 5-point Likert scale we have collected student perceptions on the structure, context specificity, ambiguity, gender orientation, and complexity of these five design problems. Currently, we are analysing the data collected to affirm that the constructs we have discussed are indeed perceived.

Conclusions

Overall, in the paper, we identify design task constructs for their potential implications during ideation investigations in classroom settings. Our preliminary investigation is designed to affirm this. Our results will be useful focusing on similar studies.

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