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Types of uncertainty and collaborative uncertainty management strategies evidenced during the engineering design process

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Abstract: Decision-making is an essential part of design thinking. One important factor that plays crucial role in design decision-making is uncertainty. The type of uncertainties faced and the ways in which they are handled can influence the decisions made. Prior work suggests that in order to engage young students effectively with the decision-making process we need to provide adequate scaffolding that helps them deal with various uncertainties that they may face, and prepare them for handling the uncertainties. Currently not much research exists on this topic. In our study, we hope to address this gap by looking at two aspects of uncertainty; (a) types of uncertainty and (b) uncertainty management strategies. The study was conducted with elementary school students working collaboratively in teams on a design problem. We developed an analytical framework that lists and explains the types of uncertainty faced and uncertainty management strategies implemented by learners while generating solutions for the design problem. Preliminary analysis done using the framework has also been discussed.

Keywords: Uncertainty, decision making, engineering design, collaboration, analytical framework

1. Introduction

One of the important skills characterizing design thinking is decision making (Dym, Agogino, Eris, Frey, & Leifer, 2005). Different researchers have either described decision making as an important process in engineering design (Dym et al., 2005; Aurisicchio, Ahmed & Wallace, 2007) or have called design to be an iterative decision-making process (Ullman, 2001; Sheppard & Jennison, 1997; Jonassen, 2012). In order to produce quality designs, engineers are required to make different kinds of decisions at different times. One important factor that plays a crucial role in the decision-making process is that of 'uncertainty'. Uncertainty is a cognitive feeling that encompasses subjective experiences of wonder, doubt or being unsure (Clore, 1992; Schwarz & Clore, 1996). It is experienced when individuals are conscious about lack of knowledge or understanding about issues related to self, others or different aspects of the environment (Jordan et al., 2012; Smithson, 1989). In (Dym et al., 2005), along with the skill of decision making, authors have also mentioned uncertainty management as an important skill in design thinking. Uncertainty acts as an important input to decision making (Ullman, 2001) and types of uncertainties faced and the manner in which they are handled can have a huge impact on the decisions that are made.

Handling uncertainty is challenging for learners and often a difficult experience, but it is important for effective decision making (Jordan et al., 2012). To improve design decision making in students, it is important to develop their uncertainty management skills. Engineering education currently underemphasizes skills related to uncertainty management in design and not much research has been done with regard to uncertainty in engineering design problem solving (Dym et al., 2005). In this paper, we focus on unfolding and characterizing uncertainty faced by elementary school students and how they cope with these uncertainties while solving engineering design problems. In our study, we looked at two aspects of uncertainty; (a) types of uncertainty and (b) uncertainty management strategies. The research questions (RQs) are as follows:

1. What are different uncertainties experienced by the learners while solving an engineering design problem?

2. How do the learners manage the uncertainties that they encounter while solving an engineering design problem?

We developed an analytical framework that lists and explains the types of uncertainty faced, and uncertainty management strategies implemented by learners while solving engineering design problem.

2. Literature Review

In the literature of design decision-making, uncertainty is generally classified into two types: (a) aleatory and (b) epistemic uncertainty (Nikolaidis, Ghiocel, & Singhal, 2004). Aleatory uncertainty is related to the variability inherent in the systems. This uncertainty is also called irreducible uncertainty. Epistemic uncertainty is described by subjectivity, lack of information or ignorance. Ullman (2001) has used the term, 'noise' for defining uncertainty in the context of design decision making. He calls conditions like, unknown criteria, lack of knowledge, restricted time for evaluating alternatives and inability to obtain peer agreement as imperfections that cause uncertainty. Dym et al. (2005), says that engineering design is always conducted with uncertainties of incomplete information, ambiguous objectives and imperfect models.

Researchers across different domains have done work on different aspects of uncertainty. According to a review of 102 self-reports of decision making under uncertainty (Lipshitz & Strauss, 1997), types of uncertainty is classified as incomplete information, inadequate understanding, and undifferentiated alternatives. Along with conceptualizing uncertainty, the paper also lists different uncertainty management strategies like reducing uncertainty, acknowledging uncertainty and suppressing uncertainty. In (McManus & Hastings, 2005), authors have developed a framework for understanding uncertainties in context of complex engineering systems. This framework has elements under four categories, namely, uncertainty, risks and opportunities, mitigations or exploitation, and outcome. Their view of uncertainty aligns with the concept of 'incomplete information'. Different authors have similar classifications although expressed in different formats (Lipshitz & Strauss, 1997).

Various empirical studies have investigated uncertainty in different domains in the context of individual and collaborative setting. Jordan & McDaniel (2014) investigated the influence of peer interaction on student's methods of dealing with uncertainty. This paper talks about managing uncertainty using socially supportive and socially unsupportive peer responses. Similarly, Radinsky (2008) demonstrated introduction of uncertainty into discussions, by sixth-grade students. In (Metz, 2004), a study was conducted on second, fourth and sixth-grade students involved in collaborative tasks of designing and conducting science experiments. Authors investigated expressions of uncertainty and strategies to resolve them at the individual level. In (Hartner-Tiefenthaler, Roetzer, Bottaro & Peschl, 2018), authors analyzed relational and epistemological uncertainty and their interaction in a collaborative learning process.

In regard to the educational context, though researchers have investigated the role of uncertainty with respect to constructs like learning (Hartner-Tiefenthaler et al., 2018) but, the research on understanding the role of uncertainty in design decision, is still lacking. In our study, we attempt to find types of uncertainty and uncertainty management strategies implemented by learners in the context of engineering design. This would be our first step in understanding the role of uncertainty student's design decision making processes.

3. Method

3.1 Sample and Data Collection

Participants of the study were 13 sixth grade students, 5 girls and 8 boys, of a science class in a private urban school in the Middle Western region of the USA. The demographic being; 97% white students followed by 2% students from two or more races, 1% Asian students and less than 1% of Hispanic, Native Indian and Black students. Five teams of students were formed by the teacher of the class, Mr K., three teams (teams T2, T3 and T4) consisting of three students and two teams (teams T1 and T5) consisting of two students each. The teams were then asked to work on the design problem discussed

below. The data used in our study was originally collected as part of a larger research project aimed at exploring learner's engineering design processes. Dedicated cameras were incorporated for each team to capture students' interaction, their gestures, and indirect references to design elements. For present study, we use the video recordings and transcript of the students' conversation captured in the video recordings to answer our research questions.

Students had to design a plumbing system for a home with one floor, total of three taps with water supply from the city at 60 psi. The teams were to serve as "plumbing companies" competing to win the bid for building the plumbing system of this house. The teams were asked to build an optimal plumbing system with low cost and a minimum of 10 psi at each tap in the house.

3.2 Data Analysis

Conversation of five teams (teams T1 consisting of students S1 and S2, T2 consisting of students S3, S4, and S5, T3 consisting of students S6, S7, and S8, T4 consisting of students S9, S10 and S11, and T5 consisting of students S12 and S13) were analyzed in this study. We analyzed the transcripts based on the literature discussed above and also used the bottom-up content analysis approach to develop and refine our own analysis framework (Mayring, 2000).

An initial framework was developed for analyzing the data. This framework consisted of codes for characterizing the types of uncertainties and uncertainty management strategies. To build this initial framework, different research papers related to uncertainty referred previously were used. Two broad types of uncertainty – Content and Relational uncertainty and five broad uncertainty management strategies – Reduce, Acknowledge, Suppress, Maintain and Increase uncertainty emerged as part of our framework. An iterative refinement process of the initial framework started with analysis of team T1's conversation. Occurrences of uncertainty and management strategies were identified by the first researcher and the initial framework was updated. This refined framework was then used by another researcher to validate the categories and definitions. This led to another round of refinement and revision which involved discussion about the instances where there were conflicts. The process continued until an agreement about the categories in the framework was reached. Table 1 show the final analysis framework obtained after the data analysis. Each category is explained in Table 2.

4. Findings and Discussion

The data analysis phase revealed high prevalence of student's uncertainty while solving design problems. Teams faced two forms of uncertainty: Content and Relational uncertainty. Three broad types of content related uncertainty faced by the teams were: (a) Incomplete information, (b) Inadequate understanding, and (c) Undifferentiated alternatives. . Relational uncertainty was expressed at two levels: (a) Related to self and (b) Related to other. (Refer Table 1 for further categorization).

Results related to RQ 1: A total of 98 instances of uncertainty were identified in 5 transcripts.

Table 1

Analytical framework listing types of uncertainty and uncertainty management strategies.

TYPES OF UNCERTAINTY				
Content Uncertainty			**Relational Uncertainty**	
1. Incomplete information# a. lack of knowledge* b. lack of definition* c. statistically characterized phenomenon^ d. known unknowns# *2. Inadequate understanding** *3. Undifferentiated alternatives#*			1. Related to self ** 2. Related to other**	
STRATEGIES FOR MANAGING UNCERTAINTY				
Reduce uncertainty	**Acknowledge uncertainty**	**Supress uncertainty**	**Maintain uncertainty**	**Increase uncertainty**

1.	*Collect information#*	1.	*Use of risk assessment decision models^*	1.	*Ignore uncertainty#*	1.	*Delay certain action, evaluation or decision#*	1.	*Open the problem space**
2.	*Solicit advice#*	2.	*Prefer or develop reversible courses of actions^*	2.	*Rely on 'intuitions'#*	2.	*Expressing doubt repeatedly***	2.	*Open the solution space**
3.	*Seek consensus#*			3.	*Play gamble^*				
4.	*Observations***								
5.	*Experimentation**								
6.	*Analysis***								
7.	*Mental simulation#*								
8.	*Explanation#*								
9.	*Express relational dissatisfaction***								

 # Retained from the initial framework as it is: No modification was done in the definition of these codes during the data analysis process.

* **Got updated in the course of analysis**: Definitions of these codes were modified during the data analysis process.

** **Added to the initial framework**: These codes were not identified during formation of initial framework and were obtained during data analysis process.

^ **Not evident in our data:** These codes were identified during formation of initial framework but were not evident in data analysed for this study.

Table 2

Explanation of different categories of the framework

TYPES OF UNCERTAINTY

Content Uncertainty: Uncertainty pertaining to the problem being solved. Following are the types of content related uncertainty.

1. *Incomplete information*: Uncertainty stemming from lack of information is the most frequently cited type of uncertainty. It refers to uncertainty due to factors like unknown or partially known facts or information, non-specified information about problem in hand etc.
2. *Inadequate understanding*: A decision maker may have all the required information but there could be uncertainty due to factors like abundance of information, conflicting or ambiguous information, inability to use information because of the novelty of the problem etc.
3. *Undifferentiated alternatives*: Uncertainty due to equally attractive or unattractive options or alternatives.

Relational Uncertainty*:* Uncertainty pertaining to interactional challenges and opportunities including issues concerning the identity of one's self, peers or group members. We classify relational uncertainty as:

1. *Related to self:* Feeling of doubt related to self, for e.g., doubt on self-ability, role or place in the team etc.
2. *Related to other*: Feeling of doubt related to other group member(s), e.g., doubt on their ability or their ideas etc.

STRATEGIES OF COPING WITH UNCERTAINTIES

1. *Reduce uncertainty*: Reducing uncertainty means to lessen or decrease the current state of uncertainty or completely removing it. Different tactics for reducing uncertainty include strategies like collecting information from different sources, taking advice from peers or experts, experimenting via systematic testing or trial and error method, etc.
2. *Acknowledge uncertainty:* Acknowledging uncertainty means, taking uncertainty into account when choosing a course of action and preparing to avoid or confront the potential risks that it can cause. It includes tactics like
3. *Supress uncertainty*: Uncertainty can be suppressed by following tactics like acting as if 'under certainty'. Ignorance includes actions like dismissing the introduced uncertainty and moving, making guess without justification, etc.
4. *Maintain uncertainty*: It means continuing with the state of uncertainty. It may include tactics like delaying certain action, evaluation or decision.
5. *Increase uncertainty*: It means further increasing or intensifying the state of uncertainty. It includes tactics like introducing new parameters which are related to the problem in hand etc. or purposefully seeking multiple alternatives.

Out of which 20% were of type 'Relational uncertainty' and remaining 80% were of type 'Content uncertainty'. It was further found that among different types of content uncertainty; 'Inadequate understanding' was the most frequently experienced type (50% of the total uncertainty types encountered). Figure 1-(a) shows the overall percentage of different types of uncertainty faced by the five teams.

Frequency counts of different types of uncertainty encountered individually by the five teams are shown in figure 1-(b). Major differences among the five teams were observed in case of uncertainty of types, 'Lack of knowledge' and 'Lack of definition.' Teams T1 and T5 faced very less uncertainty related to the type 'Lack of knowledge' (4% and 7% respectively, of the total uncertainties faced by the teams individually) and faced high uncertainty related to type, 'Lack of definition' (23% and 20% respectively) in comparison to the other teams.

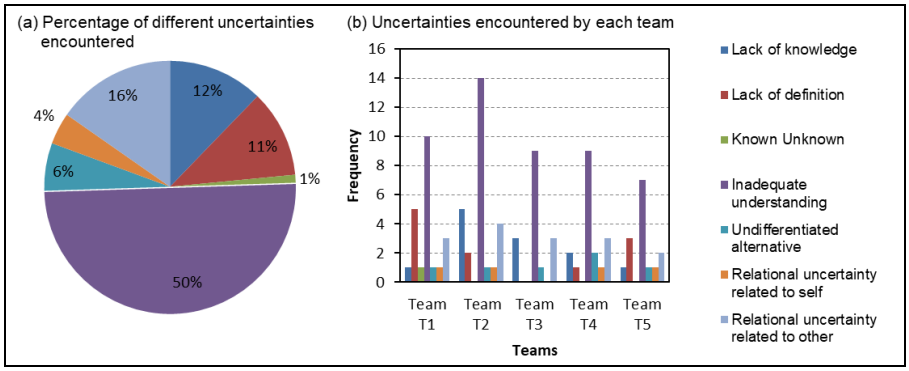

Figure 1. Types and frequency of uncertainties encountered. (a) Overall Percentage of different types of uncertainty encountered by the teams while solving design problem. (b) Frequency counts of different types of uncertainty encountered individually by the five teams

Results related to RQ 2: With respect to uncertainty management strategies, it was found that the five teams used 5 broad types of strategies. These were – Reduce, Acknowledge, Maintain, Suppress, and Increase. Only one instances related to the strategy, 'Acknowledge uncertainty' was found in the data. 62% of the times, the students tried to reduce uncertainty, using the tactic of 'Analysis' for the maximum number of times. The overall percentage of different uncertainty management strategies used by the teams is shown in figure 2-(a). Frequency of each type of uncertainty management strategies implemented by the five teams is shown in figure 2-(b). We further found that for many instances, the teams used a combination of different uncertainty management strategies to cope up with the uncertainties faced (e.g., Analysis+ Increase solution space+ Explanation, Analysis+ Experimentation+ Observation).

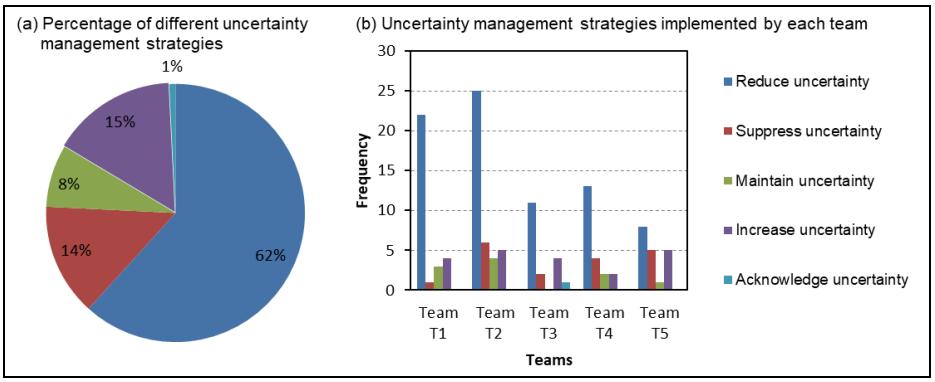

Figure 2. Types and frequency of uncertainty management strategies. (a) Percentage distribution of different uncertainty management strategies used by the teams. (b) Frequency of each type of uncertainty management strategies implemented by the five teams

We investigated subjective experiences of content and relational uncertainty faced by elementary school children and how they coped with these uncertainties. We found that the analytical framework developed in this study can help in providing meaningful insights into important questions related to decision making like, "What role does uncertainty play in design decision making?", " How can uncertainties be incorporated in collaborative learning scenarios to facilitate decision making ?".

In our present study, observations were made where the team members worked individually for certain amount of time in the decision making process and the uncertainties faced by the team during that time decreased considerably. From the preliminary analysis, it seems that collaboration may have had an impact on the uncertainty factor in decision making.

Many instances have also indicated that uncertainty has triggered important steps of robust decision making as described by Ullman (2001). Further investigation on these observations would be helpful in understanding dynamics of uncertainty management in decision making. Therefore, in order to understand the role of uncertainty in decision making, an in-depth investigation is needed on the

similar lines and the formation of the analytical framework done in this paper, is the first step towards finding the answers to such important questions related to uncertainty and decision making in design.

5. Conclusions

In this paper, we developed an analytical framework that lists and explains the types of uncertainty faced and uncertainty management strategies implemented by learners while engineering design problems. This is the first step towards understanding the dynamics of uncertainty and decision making in engineering design. By knowing what kind of uncertainties students face, in what context and in what situations, will help in developing solutions for effective management of uncertainty in design process. Understanding the role that uncertainty play (both positive and negative) in decision making process, will help in devising strategies of coping with uncertainties, as well as, of how we can make use of uncertainties for helping students in making appropriate design decisions. As a future work, we plan to use the framework obtained by the analysis done in this paper, to answer important research questions related to uncertainty in the context of design decision making, like the ones discussed in the findings and discussion section.

References

Aurisicchio, M., Ahmed, S., & Wallace, K. M. (2007, January). Improving design understanding by analyzing questions. In *ASME 2007 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference* (pp. 307-317). American Society of Mechanical Engineers.

Clore, G. L. (1992). Cognitive phenomenology: Feelings and the construction of judgment. *The construction of social judgments*, *10*, 133-163.

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.

Hartner-Tiefenthaler, M., Roetzer, K., Bottaro, G., & Peschl, M. F. (2018). When relational and epistemological uncertainty act as driving forces in collaborative knowledge creation processes among university students. *Thinking Skills and Creativity*, *28*, 21-40.

Jonassen, D. H. (2012). Designing for decision making. *Educational technology research and development*, *60*(2), 341-359.

Jordan, M. E., Schallert, D. L., Park, Y., Lee, S., Chiang, Y. H. V., Cheng, A. C. J., ... & Lee, H. (2012). Expressing uncertainty in computer-mediated discourse: Language as a marker of intellectual work. *Discourse Processes*, *49*(8), 660-692.

Jordan, M. E., & McDaniel Jr, R. R. (2014). Managing uncertainty during collaborative problem solving in elementary school teams: The role of peer influence in robotics engineering activity. *Journal of the Learning Sciences*, *23*(4), 490-536.

Lipshitz, R., & Strauss, O. (1997). Coping with uncertainty: A naturalistic decision-making analysis. *Organizational behavior and human decision processes*, *69*(2), 149-163.

Mayring, P. (2000). Qualitative content analysis. Basics and techniques (7th edition, first edition 1983). Weinheim: German Studies publishing house.

McManus, H., & Hastings, D. (2005, July). 3.4. 1 A Framework for Understanding Uncertainty and its Mitigation and Exploitation in Complex Systems. In *INCOSE international symposium* (Vol. 15, No. 1, pp. 484-503).

Metz, K. E. (2004). Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cognition and Instruction*, *22*(2), 219-290.

Nikolaidis, E., Ghiocel, D. M., & Singhal, S. (Eds.). (2004). *Engineering design reliability handbook*. CRC Press.

Radinsky, J. (2008). Students' roles in group-work with visual data: A site of science learning. *Cognition and Instruction*, *26*(2), 145-194.

Schwarz, N., & Clore, G. L. (1996). Feelings and phenomenal experiences. *Social psychology: Handbook of basic principles*, *2*, 385-407.

Sheppard, S., & Jennison, R. (1997). Freshman engineering design experiences and organizational framework. *International Journal of Engineering Education*, *13*, 190-197.

Smithson, M. (1989). Cognitive Science. Ignorance and uncertainty: Emerging paradigms.

Ullman, D. G. (2001). Robust decision-making for engineering design. *Journal of Engineering Design*, *12*(1), 3-13.

Wood, W. H. (2004). Decision-based design: a vehicle for curriculum integration. *International Journal of Engineering Education*, *20*(3), 433-439.