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Bridging the Gap Between Academia and Industry in Approaches for Solving Ill-Structured Problems: Problem Formulation and Protocol Development

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Work in Progress: Collaborative Research: Bridging the Gap between Academia and Industry in Approaches for Solving Ill-Structured Problems

Abstract

One of the main skills of engineers is to be able to solve problems. It is generally recognized that real-world engineering problems are inherently ill-structured in that they are complex, defined by non-engineering constraints, are missing information, and contain conflicting information. Therefore, it is very important to prepare future engineering students to be able to anticipate the occurrence of such problems, and to be prepared to solve them. However, most courses are taught by academic professors and lecturers whose focus is on didactic teaching of fundamental principles and code-based design approaches leading to predetermined "right" answers. Most classroom-taught methods to solve well-structured problems and the methods needed to solve ill-structured problems are strikingly different. The focus of our current effort is to compare and contrast the problem solving approaches employed by students, academics and practicing professionals in an attempt to determine if students are developing the necessary skills to tackle ill-structured problems. To accomplish this, an ill-structured problem is developed, which will later be used to determine, based on analysis of oral and written responses of participants in semi-structured interviews, attributes of the gap between student, faculty, and professional approaches to ill-structured problem solving. Based on the results of this analysis, we will identify what pedagogical approaches may limit and help students' abilities to develop fully-formed solutions to ill-structured problems.

This project is currently ongoing. This work-in-progress paper will present the study and proposed methods. Based on feedback obtained at the conference from the broader research community, the studies will be refined. The current phase includes three parts, (1) problem formulation; (2) protocol development; and (3) pilot study. For (1), two different ill-structured problems were developed in the Civil Engineering domain. The problem difficulty assessment method was used to determine the appropriateness of each problem developed for this study. For (2), a protocol was developed in which participants will be asked to first solve a simple problem to become familiar with the interview format, then are given 30 minutes to solve the provided ill-structured problem, following a semi-structured interview format. Participants will be encouraged to speak out loud and also write down what they are thinking and their thought processes throughout the interview period. Both (1) and (2) will next be used for (3) the pilot study. The pilot study will include interviewing three students, three faculty members and three professional engineers. Each participant will complete both problems following the same protocol developed. Post-interview discussion will be held with the pilot study participants individually to inquire if there were any portions of the tasks that are unclearly worded or could be improved to clarify what was being asked. Based on these results the final problem will be chosen and refined.

Keywords: problem-solving, verbal protocol analysis, ill-structured problem

I. Introduction

The National Academy of Engineering (NAE) [1] defines attributes of the engineer of 2020 as follows: "He or she will aspire to have the ingenuity of Lilian Gibbreth, 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 means that being an engineer is multifaceted, where expectations include possessing a variety of abilities such as professionalism, leadership, ethical standards, communication, creativity, management, listening and problem-solving skills. In order to prepare engineering students for their future professional career and to foster and develop the aforementioned skills and qualities, fundamental aspects of the engineering curriculum should be taken into consideration.

It can be argued that the primary skill needed by engineers throughout their professional career is the ability to solve problems. Engineers, by definition, regularly tackle complex problems and attempt to find the best solutions to those given problems with the resources available to them. However, throughout a student's studies in undergraduate engineering courses, they are most frequently asked to solve well-structured problems. In university settings, engineering students are usually asked to solve well-structured problems as part of their coursework, such as those often found at the end of textbook chapters [2]. These problems are often situated in artificial problem contexts [3], and have single and definitive answers [4], [5]. These well-structured problems outline constraints and goals, and possess clearly defined solutions, and as Jonassen [5] points out, are typically domain-dependent with specific, prescribed solution processes.

However, after graduating, upon beginning to work as an engineering industry professional, the problems that engineers encounter on a daily basis are inherently ill-structured. Unlike most of the well-constrained problems, ill-structured problems are complex, defined by non-engineering constraints, are missing information, and contain conflicting information [6]. Ill-structured problems also yield multiple possible solutions and goal states as there are multiple solution paths for the solver to take.

The aim of this study is to compare and characterize the problem-solving approaches of students, academic faculty, and practicing engineers in the field of Civil Engineering. It investigates differences in problem-solving strategies adopted by undergraduate students, professors and practicing engineers when faced with an ill-structured problem, as well as the impact of demographics, learning styles and creativity. As a result of the findings of this research, approaches will be proposed to help students develop the skills they need to approach ill-structured problems such as those that these students will ultimately face as industry professionals.

II. Literature Review

Since the 1960s, there has been a remarkable increase in the interest in the process of problem solving, which, as Jonassen [5] defines, "is more complex than the sum of its component parts and engages a variety of cognitive components". The process of problem solving consists of a number of elements such as domain knowledge (rules, principles, and concepts), structural knowledge (information networking, mental models), metacognitive skills (assessing progress and prior knowledge), applicative skills (constructing and applying arguments and analogizing) as well as motivation and knowledge about self [5], [7].

With this growing interest in problem solving, it has come to be studied in the engineering domain, including how engineers – predominantly students and professionals – approach real-world problems that they may face at school or in industry. Ill-structured problems have received an increasing amount of interest in the past two decades as it has been identified that real world problems that graduating engineering students will face when they begin to work in industry are more commonly ill-structured than well-structured. Research and journals regarding ill-structured problem solving (e.g., [2], [5], [8], [9], [10], [11], [12] [13], [14], [15], [16], [17]) have covered a range of topics, including problem definition and formulation, verbal protocol methods, and problem solving research studies.

Studies have discussed various aspects of the differences between, particularly, students and professionals in the solving of ill-structured problems. Differences have been found in the use and type of analogies and whether they were schema-driven or case-driven (e.g., [8], [18], 19]), time spent in the problem scoping and problem solution space (e.g., [8], [9], [20], [21]), and the breadth of problem solving (e.g., [9]). These studies were all focused on students and professionals, but have not included faculty. Consequently, there is a lack of data on how faculty prefer to solve ill-structured problems, the correlation between their preferences and their pedagogical approaches, and the impact on faculty approaches on a student's development of problem-solving skills.

Existing research has previously compared groups such as undergraduate freshman and seniors [14], students to expert practitioners [9] or students to professors [11]. A relative expert approach involves studying a group presumed to be more knowledgeable in a task compared to a group presumed to be less knowledgeable [9]. Engineering students often lack a deep understanding of the concepts and principles that underlie their areas of training [22]. Equally important, engineering faculty often underestimate the difficulty that students face in understanding many of these concepts [22]. Thus, this research includes not only experts (practicing engineers) and novices (undergraduate students) but the professors (academic faculty/researchers) who are responsible for educating students and preparing them for their future careers in the engineering industry. Additionally, this research is unique in that it specifically focuses on Civil Engineering and its sub-disciplines and also considers any correlation between individual creativity and problem solving approaches.

In short, a growing amount of research shows the differences between students and professional engineers in terms of approaches for solving ill-structured problems. Based on these differences across different groups, it is clear in these studies that expert engineers produce higher quality solutions and consider more alternative solutions and they differ from novice engineers and students on their problem scoping and information gathering. Pertaining to this gap between academia and industry, research is needed to explore characteristics of the problem solving approaches of students and professionals to better understand what factors may influence these approaches, and to gain insight into how to better teach undergraduate students how to solve ill-structured problems. In order to extend the analysis of problem solving approaches to a larger group of participants, this study examines faculty members as well as students and practicing engineers. It is hypothesized that these three groups of participants will differ both quantitatively and qualitatively in their problem-solving processes.

III. Methodology

In this study, we plan to conduct a comparative analysis of undergraduate students, faculty members, and practicing engineers and their approaches to an ill-structured problem using verbal protocol analysis to document and assess problem solving approaches and evaluate differences between the three groups. Thus far, we have worked on the development of the ill-structured problems and are currently in the pilot-test phase. A summary of the procedures followed thus far for problem formulation and pilot testing are included in Part A of the methodology. This is followed by the planned methods to be followed for the remainder of the study in Part B-D.

A. *Procedures for Problem Formulation*

The first task includes the design of ill-structured problems that could be presented to participants to better understand their approaches to solving ill-structured problems. First, the research team, consisting of four faculty members, one graduate student and one undergraduate research student, brainstormed contexts and drafted a short description of potential ill-problems relevant to Civil Engineering. This process led to a wide variety of problems, including problems such as improving university campus facilities, maintaining roadways with high-freeze thaw cycles, designing parking lots, reviewing of structural, mechanical, electrical and plumbing drawings, and others. Through this process, the team generated over 15 different ill-structured problems. Second, the team selected problems to be further developed to include more detailed problem statements and constraints. Problems were selected based on two criteria (1) types of problems (i.e., decision making, troubleshooting and design problem) and (2) civil discipline (i.e., construction, geotechnical, materials, environmental, structural and transportation). The goal was to select problems that contained multiple components of the two criteria categories. Through the process of compiling data and team discussions, the following four problem topics were selected: (1) removing trash from a river, (2) removing gum from a city park, (3) designing an outdoor office space, and (4) removing trash from the ocean.

Next, the four selected problems were further developed. The research team member who initially came up with the problem in the brainstorming phase led the effort in further developing the problems (i.e., including the problem statement, stakeholders, constraints, diagrams, etc.). Jonassen's [5] paper was used as a reference to include features of ill-structured problems in each of four problems. We utilized an iterative process, such that the lead research team member completed developing the problem, other research team members provided feedback and commented on the problem, and this feedback was addressed by the lead member.

Finally, the four problems were narrowed to two problems. In this process, the research team reached out to the project advisory board members which include civil engineers (both in academia and industry) and educational research scientists. The research team created an online Qualtrics survey which included copies of the four problems along with a series of Likert-type questions and asked the advisory board to provide responses and feedback on these problems using this online platform. In order to reduce any bias, the team randomized the order in which the four problems were presented to each advisory board member. The survey included questions regarding the amount of technical knowledge required to complete the problem, level of difficulty to understand concepts to attain a solution, and amount of Civil Engineering discipline-specific knowledge needed develop a solution to the problem. Questions also included an assessment of the number of conceivable solutions, a level of investment felt by the reader to solve the problem, and whether a solution could be developed to the problem in the proposed 30 minute timeframe.

We further asked the advisory board members to rank the four problems in the order in which they would recommend for the pilot study and their reasons for the rankings. A total of seven advisory board members responded to the survey. After reviewing the results, the team decided to pilot test both the river trash problem and gum removal problem. These two problems were selected based on their consistency in receiving high ranks, high relevance to the civil engineering discipline, and the perceived multiple number of conceivable solutions.

The next task for the research team is to pilot test these two selected problems. Specifically, the team will ask several civil engineers, including both faculty, and practicing engineers, and current engineering students to develop a solution to the problem in allotted 30-minute time, while speaking out loud regarding their problem solving process and solution paths. The goal of this task will be to check the feasibility of the problem and the questions in an environment that mimics that of what is planned for the final interview stage of this research, and receive further feedback on the problems before the final data collection process begins.

B. *Participant Selection*

Following the pilot study, a minimum of 50 undergraduate students, 25 faculty members and 25 professional engineers will be recruited and asked to solve the chosen ill-structured problem. A purposeful maximum variation sampling method will be used to recruit and select participants in this study [23], [24], as this method encourages the selection of participants that are likely to demonstrate variation in the studied topic. Student participants will be recruited from two Midwestern universities, including a large multi-disciplinary institution and a smaller engineering-focused school. A range of levels of undergraduate students from sophomore to senior ranking will be included to enable an understanding of the impact of education level on their problem solving methods and abilities. All professional participants will identify as Civil Engineers and either have a Professional Engineer (PE) license, or 5+ years of post-bachelorette experience. Faculty members will be recruited from variety of sub-disciplines of Civil Engineering and from variety of institutions, backgrounds, and levels of industry experience outside of academia.

C. *Procedures for Data Collection*

Each participant will be interviewed individually in a quiet setting. They will be permitted to have several sheets of blank paper. Each participant will first be asked to solve a short practice problem prior to receiving the actual ill-structured problem statement to familiarize themselves with the process of thinking aloud (i.e. verbal protocol). This practice problem will be a well-structured word problem on a Civil Engineering topic which requires the use of basic math and with an anticipated completion time of less than five minutes. The problem is meant to allow participants to warm up and practice verbalizing their thought process prior to completing the ill-structure problem. Verbalizing the problem-solving process continuously throughout the interview will be key in yielding valuable data.

Following this practice problem, the participants will be provided with a Civil-Engineering related ill-structured problem and again asked to speak aloud to explain their thought processes throughout the 30-minute allotted time to provide a conceptual solution to the problem. Interviewers will prompt participants to continue verbalizing their thought process throughout the solution when participants either stop verbalizing while writing or if they pause for greater than 20-25 seconds. Participants will not be permitted to have access to the Internet, or any additional sources of information such as textbooks. Each interview will be recorded via video recorder and smart pen device, transcribed and analyzed to assess the differences in perceptions of problem solving, enrich our understanding of problem solving process, and better understand what approaches participants adopt as they solve a problem.

In addition to the solving of the ill-structured problem, participants will complete three surveys discussing basic demographic information, their preferred learning style, and an assessment of creativity. The surveys will provide quantitative and qualitative information for comparing participants' problem solving approaches. Following completion of the ill-structured problem, participants will be asked to complete a final survey regarding self-efficacy.

D. *Data Analysis*

Both quantitative and qualitative analyses of the collected data will be carried out in order to examine problem solving approaches adopted by participants and to assess the variations in problem solving methodologies. After gathering all of the recordings and conducting interviews, the first step will be to transcribe the recorded participant's solutions to the problem to analyze the data using the recorded files. The transcribed text will then be segmented into utterances and coded. First, the large units of analysis, *think-aloud utterances* will be identified. These include a string of words spoken by participants, followed by a period of silence [25]. Additionally, the written graphical materials will be annotated and connected with the interview transcripts, as well as any notes made by the interviewer. Written responses will also be analyzed for creativity and the use of other written problem-solving techniques.

Next, a code or set of codes will be assigned to each of the segments. To ensure consistency of coding, there will also be inter-rater reliability (IRR) checks conducted among coders to check for agreement; for the initial interview transcripts an 80% agreement goal is planned. If 80% is not achieved, the final coding will be determined through discussion. Upon reaching an agreement of 80% (e.g., Atman et al., 2007), the remaining interview transcripts will be divided among the coders. The coding will be done blindly with respect to the participants' attributes, including their level of experience. The code(s) assigned to each segment of each transcript will consist of a number of constructs – use of analogies (within-domain analogy and between-domain analogy), metaphor, problem space, solution space and overlapping space, number of different solutions considered, complexity of solutions, level of confidence and self-efficacy, and creativity.

The analysis of qualitative data will reveal patterns of how engineering students, faculty and professionals solved problems and what they focused on as they solved ill-structured problems. The examination of quantitative data, using independent samples t-test and multiple regression analyses, will determine the relationship between problem solving steps (e.g., amount of time spent in different spaces) and participant attributes, and specifically on the effect of participants' level of experience, intellectual diversity, university breadth of education and sub-disciplines on the approaches to problem solving. These analyses will determine the different processes that students, professors and professionals undertake to solve ill-structured problems and the influential attributes of engineers beyond the number of years of experiences in the field.

IV. Expected Outcomes

At the end of this study, we expect to identify differences between problem solving approaches of students and professors and those of engineering industry professionals. Based on the findings we will create variety of educational resources such as a guidebook, including recommendations, a series of activities, and samples of ill-structured problems for both engineering faculty and undergraduate students and modules that will be shared with the engineering education community. The results of this work will contribute to the scientific and educational community in the following ways: (1) improved understanding of the differences between faculty and professional approaches to ill-structured problems, (2) identification of main differences and contributing factors to the discrepancies between students and professionals, (3) recommendations based on analysis of a significant number of interviews from a diverse set of professionals, students and faculty of how to better teach ill-structured problem solving to improve students' preparedness for the engineering industry upon graduation.

References

[1] National Academy of Engineering, U.S., *The engineer of 2020: visions of engineering in the new century*. Washington, DC: National Academies Press, 2004.

[2] D. H. Jonassen, "Toward a design theory of problem solving," *Educational Technology Research and Development*, vol. *48*(4), pp. 63-85, 2000.

[3] S. Toy, "Online ill-structured problem-solving strategies and their influence on problem-solving performance," Ph.D. dissertation, Dept. Education, Iowa State Univ., Ames, IA, 2007.

[4] J. Bransford and B. Stein, *The IDEAL problem solver*. New York: W. H. 95 Freeman, 1984.

[5] D. H. Jonassen, "Instructional design models for well-structured and III-structured problem-solving learning outcomes," *Educational Technology Research and Development*, vol. 45(1), pp. 65-94, 1997.

[6] D. H. Jonassen, J. Strobel, and C. B. Lee, "Everyday problem solving in engineering: Lessons for engineering educators," *Journal of Engineering Education*, vol. 95(2), pp.139-151, 2006.

[7] D. H. Jonassen and M. Tessmer, "An outcomes-based taxonomy for the design, evaluation, and research of instructional systems," *Training Research Journal,* 1996.

[8] R. A. Dixon and S. D. Johnson, "Experts vs. novices: differences in how mental representations are used in engineering design," *Journal of Technology Education*, vol. 23(1), pp. 47-65, 2011.

[9] C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg, and J. Saleem, "Engineering design processes: A comparison of students and expert practitioners," *Journal of engineering education*, vol. 96(4), pp. 359-379, 2007.

[10] C. J. Atman and K. M. Bursic, "Verbal protocol analysis as a method to document engineering student design processes," *Journal of Engineering Education*, vol. *87*(2), pp. 121-132, 1998.

[11] K. L. Taylor and J. P. Dionne, "Accessing problem-solving strategy knowledge: The complementary use of concurrent verbal protocols and retrospective debriefing," *Journal of Educational Psychology*, vol. *92*(3), pp. 413-425, 2000.

[12] N. Shin, D. H. Jonassen, and S. McGee, "Predictors of well-structured and ill-structured problem solving in an astronomy simulation," *Journal of research in science teaching*, vol. *40*(1), pp. 6-33, 2003.

[13] L. J. Ball, T. C. Ormerod, and N. J. Morley, "Spontaneous analogising in engineering design: A comparative analysis of experts and novices," *Design studies*, vol. *25*(5), pp. 495-508, 2004.

[14] C. J. Atman, M. E. Cardella, J. Turns, and R. Adams, "Comparing freshman and senior engineering design processes: An in-depth follow-up study," *Design studies*, vol. *26*(4), 2005, pp. 325-357, 2005.

[15] J. N. Byun and W. G. Lee, "Development of Ill-Structured Problems for Elementary Learners to Learn by Computer-Based Modeling Tools," *International Journal of Computer Theory and Engineering*, vol. *6*(4), p. 292, 2014.

[16] A. Kothiyal, B. Rajendran, and S. Murthy, "Delayed Guidance: A Teaching-Learning Strategy to Develop Ill-Structured Problem Solving Skills in Engineering," In *Learning and Teaching in Computing and Engineering (LaTiCE): 2015 International Conference, IEEE* 2005, pp. 164-171.

[17] J. O. Riis, M. Achenbach, P. Israelsen, P. Kyvsgaard Hansen, J. Johansen, and J. Deuse, "Dealing with complex and ill-structured problems: Results of a Plan-Do-Check-Act experiment in a business engineering semester," *European Journal of Engineering Education*, vol. *42*(4), pp. 396-412, 2017.

[18] J. Daugherty and N. Mentzer, "Analogical reasoning in the engineering design process and technology education applications," *Journal of Technology Education*, vol. 19(2), pp. 7-21, 2008.

[19] J. Hey, J. Linsey, A. M. Agogino, and K. L. Wood, "Analogies and metaphors in creative design," *International Journal of Engineering Education*, vol. *24*(2), pp. 283-294, 2008.

[20] L. A. Liikkanen and M. Perttula, "Exploring problem decomposition in conceptual design among novice designers," *Design studies*, vol. *30*(1), pp. 38-59, 2009.

[21] T. A. Litzinger, P. Van Meter, C. M. Firetto, L. J. Passmore, C. B. Masters, S. R. Turns, G. L. Gray, F. Constanzo, and S. E. Zappe, "A cognitive study of problem solving in statistics," *Journal of Engineering Education*, vol. 99(4), pp. 337-353, 2010.

[22] R. Taraban, A. DeFinis, A.G. Brown, E. E. Anderson, and M. P. Sharma, "A paradigm for assessing conceptual and procedural knowledge in engineering students," *Journal of Engineering Education*, vol. *96*(4), pp. 335-345, 2007.

[23] M. D. Gall, J. P. Gall, and W. R. Borg, *Educational research: An introduction*, New York: Person Education, 2007.

[24] L. A. Palinkas, S. M. Horwitz, C. A. Green, J. P. Wisdom, N. Duan, and K. Hoagwood, "Purposeful sampling for qualitative data collection and analysis in mixed method implementation research," *Administration and Policy in Mental Health and Mental Health Services Research*, vol. *42*(5), pp. 533-544, 2015.

[25] D. K. Hartman, "Eight readers reading: The intertextual links of proficient readers reading multiple passages," *Reading Research Quarterly*, vol. 30(3), pp. 520-561, 1995.