Developing an Understanding of Civil Engineering Practitioner Problem-solving Rationale Using Multiple Contextual Representations

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Abstract

This paper presents the preliminary findings of a larger study on the problem-solving rationale associated with the use of multiple contextual representations. Four engineering practitioners solved a problem associated with headloss in pipe flow while their visual attention was tracked using eye tracking technology. Semi-structured interviews were conducted following the problem-solving interview and the rationale associated with their decisions to use a particular contextual representation emerged. The results of this study show how the rationale can influence the problem-solving process of the four engineering pracitioners. Engineering practitioners used various contextual representaions and provided multiple rationale for their decisions. Eye tracking techniques and semi-structured interviews created a robust picture of the problem-solving process that supplements previous problem-solving research.

Introduction

Within all fields of engineering, it is common for engineers to use multiple contextual representations (e.g., graphs, tables, formulas) to solve problems. For instance, when a civil engineer designs a network of pipes to convey water to a city, they will use software based on formulas learned in college engineering courses, pipe manufacturer specifications provided as tables, graphs, and figures, and other codes and specifications often presented in multiple ways. Similar contextual representations (CRs) are used in engineering courses to teach students fundamental engineering concepts. Research has shown that CRs can influence students' understanding of important engineering concepts, but less work has addressed how engineering practitioners interact with CRs as they use these concepts to solve problems. If educators are able to better understand how engineering practitioners use and navigate between various CRs, fundamental engineering concepts can be taught in a way that better prepares students for modern engineering practice. Therefore, we pose the following research question:

How do engineering practitioners describe their selection of a given contextual representation during problem solving?

To answer this question, we present a subset of data from a larger study focused on engineering practitioners' choices during problem solving. While solving a problem related to headloss in pipes, engineering practitioners' visual attention were tracked and semi-structured interviews were conducted immediately after engineers solved the problem with probing questions informed by specific features of participants' solution processes. This paper will focus in depth on the expanded stories of four individual engineering practitioners who solved one similar problem.

Literature Review

Preparing students for the realities of modern engineering practice remains both a goal and challenge of the engineering education community. Engineering students spend a bulk of their academic career solving engineering problems (Downey, 2009). It is through these problems that they learn fundamental engineering concepts that will be applied in their engineering practice.

Previous studies have highlighted important differences between novice and expert approaches to problem solving (Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007; Hurwitz, Brown, Islam, Daratha, & Kyte, 2014). Engineering practitioners spend more time gathering information, considering alternatives, and perhaps most importantly, designing. The result of these differences in activity patterns are reflected in the overall quality of the design. Additionally, research in problem solving has shown that even through practice, engineering students often struggle with the transfer of learned information to new situations (Venters & McNair, 2010).

Consequently, research has shown that engineering graduates are ill-prepared for the workplace and the complex open-ended problems that are typical of engineering design (Collins, 2008; Education et al., 2005). The problems engineering students solve in school are thought to require the same fundamental concepts that engineering professionals use in practice. However, research shows that these concepts are typically applied differently in practice which can cause practitioners to make different decisions during problem solving (Jonassen, Strobel, & Lee, 2006; Urlacher, Brown, Steif, & Bornasal, 2015). A strategic approach to understanding this misalignment is to examine how engineering practitioners solve engineering problems.

Analyzing the problem-solving process often requires the use of different interviewing and monitoring techniques. Qualitative techniques such as think-aloud and retrospective interviews have been used alongside video recordings and eye tracking (Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007; Cook, Wiebe, & Carter, 2008; Patrick, Carter, & Wiebe, 2005; Stieff, Hegarty, & Deslongchamps, 2011; Venters & Mcnair, 2010). Eye tracking methods are based on the "eye-mind" assumption (Just & Carpenter, 1980) which suggests that eye movements correlate with attentional focus and cognitive processing (Lai et al., 2013). These methods use eye trackers to capture a variety of eye movements, such as fixations, which can be recorded to better understand how visual stimuli influence the problem-solving process (Lai et al., 2013). For example, Stieff et al. (2011) used eye tracking techniques to compare the time students spent looking at individual representations and discovered that students preferred the visual and graphical representations to conceptually equivalent equations.

Eye tracking methods can also be used to enhance the validitiy of more traditional interview procedures (Lei et al., 2013). For example, while having middle and high school students solve problems, a combination of eye tracking with retrospective interviews was used to determine the salient features and student comprehension of multiple molecular representations (Cook, Wiebe, & Carter, 2008; Patrick, Carter, & Wiebe, 2005). Further, Venters and McNair used think-aloud protocols during Statics problem solving to investigate thought processes of students while problem solving. Their work determined that a student's ability to solve problems may be attributed to their individual approach to studying for a course. To date, however, approaches combining eye tracking data with qualitative protocols are underexplored.

Problem-solving research using various interviewing and monitoring techniques has uncovered valuable information about the problem-solving process. But most of this research explores what and how decisions are made during problem solving, with less attention paid to the reasons *why* a particular solution or process or, in this case, CR is used. Expanding problem-solving research to include rationale, especially with more experienced problem solvers, will offer insight into the problem-solving experiences of experts. Eye tracking methods offer a way of accessing greater insight into the experts' problem-solving process and can guide further inquiry on rationale in subsequent interviewing techniques (Lai et al., 2013). This information can be used to better understand the problem-solving process and can supplement various instructional methods.

Methods

In order to determine how an engineer and student engage with CRs during problem solving, we first developed problems we believed to be relevant to engineering workplaces. Engineering practitioners put on ASL Mobile Eye-XG eye tracking glasses and worked on three different problems related to pipe flow. The data collected from the eye tracking device provides insight into what contexts practicing engineers focus on during problem solving. Following the problem solving, a retrospective interview was conducted to determine the thought processes of the engineers during problem solving. This section describes the problem development, participant selection, data collection, and data analysis. The goals for the interviews were to determine which CR was referenced while problem solving, understand how each participant solved each problem and used the CRs, and understand why each participant chose a particular CR. This study presents a subset of a larger data set, and focuses on four individual participants.

Problem Development

Our goal was to develop problems that were both relevant to our sample and which could be solved using a limited set of CRs. To generate such problems, we conducted phone interviews with six practicing hydraulics engineers. These interviews produced a list of common problems and CRs relevant to engineering practitioners. Pipe design manuals and academic textbooks were used to gather CRs for problem development (Hydraulic Institute, 1990; Morse, 1988; Crowe, Elger, Williams, & Roberson, 2009). Using the information gathered from these interviews and academic and professional materials associated with hydraulic engineering, eight hydraulic problems with four CRs were developed. It was important to include contexts that were formulaic in nature (i.e. Hazen Williams and Darcy Weisbach), tabular, and graphical because it potentially provides insight into the preferences for the *kind of representation* that practitioners tend to prefer. A slide with all CRs and the problem statement was created and beta testing was completed with three graduate students. The four CRs are summarized in Table 1. Three of the eight problems were selected for the present study: 1) an open-ended problem, 2) a ranking problem, and 3) a multiple-choice problem.

For this study, the data from one problem will be analyzed for the four participants. The problem type analyzed in this study is an open-ended problem. The problem statement asked the participant to determine the total headloss for 1000 feet of new unlined 8-inch Schedule 40 steel pipe that is designed to carry water at a rate of 550 gallons per minute.

Table 1

Description of the four contextual representations provided to solve each problem

Contextual Representation	Format	Description
Schedule 40 Tables	Tabular	Three columns of data describing how headloss per 100 feet of Schedule 40 Steel pipe is related to velocity of fluid flow. Three pipe sizes included: 4”, 6”, and 8”.
Hazen Williams	Formula	Empirical formula that calculates the total headloss in a pipe based on pipe diameter and length, flowrate, and the Hazen Williams Coefficient from an included table.
Headloss Chart	Nomograph	Interpreted chart that provides headloss per 100 feet of pipe based on plotting the flowrate and diameter of pipe.
Darcy Weisbach	Formula	Empirical formula that calculated the total headloss in a pipe based on pipe diameter and length, fluid velocity, gravitational constant, and the friction factor which is interpreted from the Moody Diagram (provided). The Moody Diagram relates the Relative Roughness and the Reynolds number to the Friction Factor.

Participants

Participants were recruited through a purposeful snowball sampling (Biernacki & Waldorf, 1981). Civil engineers in the greater Portland, Oregon area were asked to volunteer and forward the study’s information to other potentially interested engineers. This study presents the results of four participants from the larger data set of engineering practitioners. These four engineering practitioners represent a broad range of preliminary findings. Participants were given pseudonyms for confidentiality.

Data Collection

Data collection proceeded with the three developed problems using engineering practitioners. The process required a participant to sit in front of a computer monitor that displayed the problem statement and four CR’s on a single slide. The participant wore the eye tracking equipment while they solved the problems and their eye movements and gaze patterns were collected using ETAnalysis software. During the experiment, the participants completely solved each of the presented problems while the researcher also monitored their eye gaze patterns in real time. If necessary, the participants asked clarifying questions. Once the participants had completed all three problems, the eye tracking equipment was removed and the retrospective interview was conducted and audio recorded. The questions aimed to discover the steps taken during problem solving, what CRs were used, and why decisions were made to use those CRs.

Importantly, observations made by the first author during the eye tracking portion of the interview informed probing questions during the retrospective interviews (e.g., "Is there any reason you spent so much time looking at [x] even though you noted preferring [y]?"). These additional questions provided more specific insight into the thought processes of the participants creating a more robust and complete problem-solving description.

Data Analysis

Data analysis included the analysis of the eye tracking data and the coding of the retrospective interviews. Reducing the eye tracking data is a process used to determine the amount of time each participant fixates on a particular CR. A single fixation is when the eyes focus on a single point for a 10th of a second or longer. The eye tracking data was manually reduced using the ETAnalysis software. Each CR was considered to be an Area of Interest (AOI). Once each AOI is created, the ETAnalysis calculated fixation counts for each AOI based on the gaze patterns of the participant. This data was exported into Excel and analyzed based on total fixation duration (TFD) percentages.

Percent TFDs were used to compare how much time an engineering practitioner spent referring to each CR. Considering that each participant spent varying lengths of time to solve the problem, percent TFD was used as a means to normalize results between participants. Only fixations on the four CRs were considered during this analysis. Fixations on the problem statement and outside of the monitor were not included. The results from the percent TFD describe how the problem was solved by showing what CRs were used and what percentage of the total time fixated was spent referring to each CR. The relative time spent on each of the CRs describes which CRs were important in the solution process. The CR with the highest percentage is considered the *preferred choice* for solving the problem based on the eye tracking data.

The retrospective interviews were transcribed via a professional transcription service. The coding of the retrospective interview transcripts was completed using in-vivo techniques where codes are developed from the words the participants used to describe their rationale (Saldaña, 2015). Due to the exploratory nature of this research, we used participants' words to allow findings to emerge. The coding process was completed through multiple iterations where each code was created, discussed, defined, and reapplied during a second reading of the transcripts. More specifically, following the creation of a new in-vivo code, the remaining data was also reanalyzed for the presence of the new code. Each code is a rationale for the choice of a particular CR. The generated codes, their definitions, and an example excerpt from the data is in Table 2.

Table 2

In-vivo codes, definitions, and examples from retrospective interviews

Code	Definition	Example Excerpt
Speed	This CR provides the quickest means to solve the problem.	"At first, I guess I was just gonna plug it into the equation and then I thought, hey, I could just interpolate here and that would be a lot faster."
Familiarity	This CR is more familiar to use and is often described as a comfortable choice.	"I recognize this, I know this equation, I have done this equation". You know, I would, I think yeah. Just familiarity and ... seeing that"
Accuracy	CR used based on the level of accuracy that it provides based on some engineering judgement of the participant.	"Yeah, tried to figure out what, how accurate you wanted the answer because that changes what I would use."
Simplicity	Using this CR requires less work and effort to solve the problem.	"Yeah, I went with the simplest method I could find."

Limitations

The primary limitation of the methodology used in this study is the context of the problem-solving interview. Engineering practitioners were asked to solve problems similar to academic problems while wearing eye tracking glasses and being monitored by a researcher. During the retrospective interviews, engineering practitioners would describe the context as similar to a "test-taking" situation and some would claim that this caused them to feel "rushed" and "under pressure". These experimental effects were rarely identified in the retrospective interviews, but are considered important to the limitations of this study's methodology.

Validity and Trustworthiness

To establish validity of the data in this research study, two independent data sets were used to make claims about the solution process of engineering practitioners. The combination of eye tracking and retrospective interview methods produced content validity. Both data sets seek to understand the same process but from two separate points of reference. Therefore, the triangulation and corroboration afforded by complementary methods offers a source of validity within the methodology itself. Further, multiple researchers reduced the eye tracking data and reviewed the codes generated from the interview transcripts. The eye tracking data reduction was completed by two researchers who independently determined the fixation patterns in relation to the areas of interest. The codes generated from the interview transcripts underwent intercoder agreement through the review process by three researchers. This process included multiple refinements of the code definitions where discrepancies of each code and their application were argued to agreement.

Results

To understand the data collected and how each participant engaged with the CRs, results are presented as four individual summaries for each of the engineering practitioners. The eye tracking data are reported as total percent fixations on each of the CRs. The retrospective interview data are reported as the individual rationales generated from the coding process. The retrospective interview data provides a qualitative look at the engineering practitioners' thought processes during problem solving, describing why particular CRs were used. The individual rationales are used in combination with the eye tracking results to describe the engagement of the engineering practitioners with the CRs. The combination of these two data sets shows that each of the four engineering practitioners have a unique way of engaging with the CRs. This section will describe some of the major findings from this sample which will lead into the discussion, implications, and future work sections.

Eye Tracking and Retrospective Interview Results

Eye tracking and retrospective interviews are presented together to highlight the ways these different forms of data support one another. Results for the four engineering practitioners' eye tracking and retrospective interview data show that there are rationales used to solve the problem. Based on total fixation percentages for each AOI, engineering practitioners prefer different CRs and spend varying amounts of time fixated on other CRs, as shown in Figure 1. The retrospective interview results determined that at least four different rationales are given during the problem-solving process as justification for the use of a particular CR, given in Table 2. A summary of the eye tracking and interview results are described in Table 3. The results are presented as four individual summaries for each engineering practitioner to highlight their individual engagement with the CRs.

Table 3

Summary of results for each participant

Participant	Preferred CR from Eye Tracking	Preferred CR from Verbal Recall	Rationale
Greg	Headloss Chart	Schedule 40 Tables	Simplicity, Speed
Angela	Schedule 40 Tables	Schedule 40 Tables	Familiarity, Accuracy, Speed
Brandon	Darcy Weisbach	Hazen Williams	Simplicity
Megan	Darcy Weisbach	Darcy Weisbach	Simplicity, Familiarity

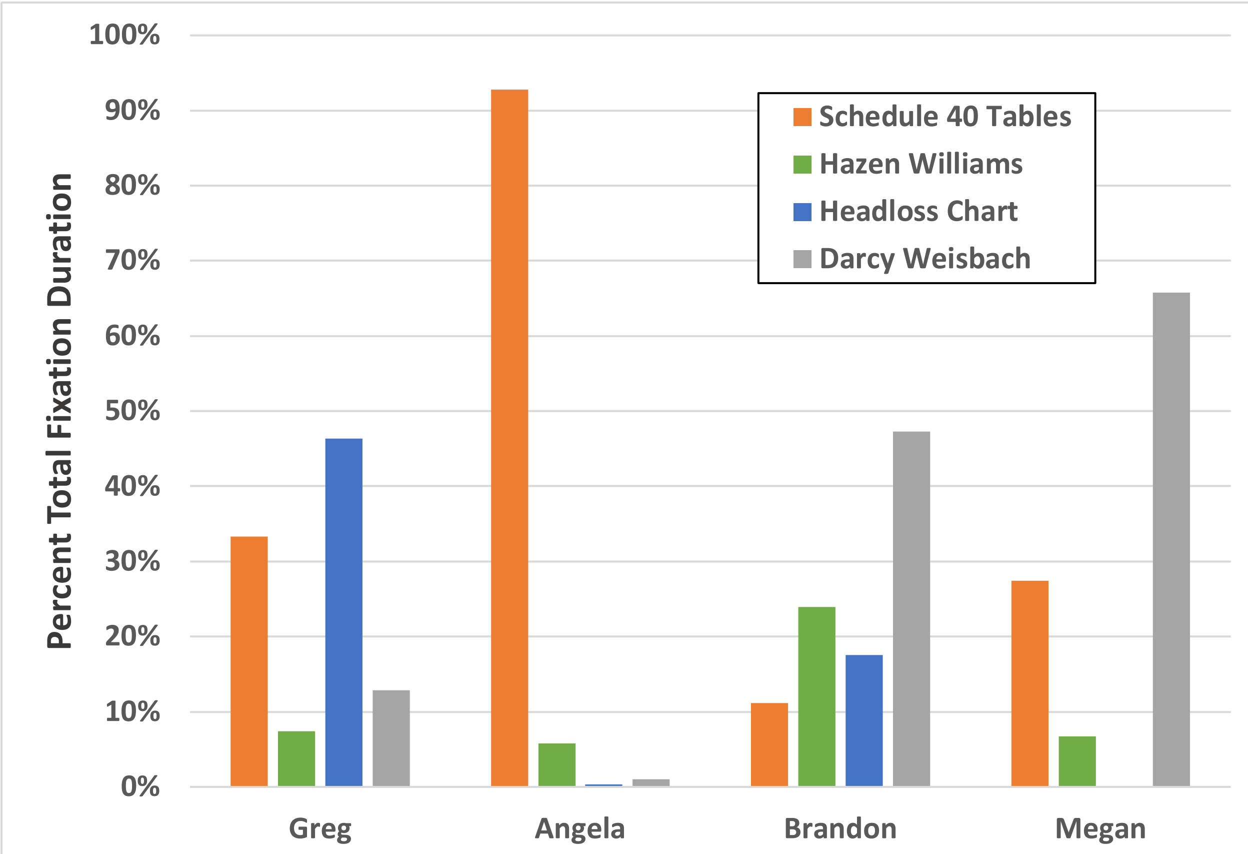

Figure 1. Total percent fixation plots of the eye tracking results for the four engineering practitioners.

Greg

Based on the total fixation percentages, Greg spent most of their time fixating on the Headloss Chart when solving the problem. They fixated on the Headloss Chart 46.4% of the time they spent solving the problem. The eye tracking data also shows that Greg spent at least 7% of their time fixated on each CR and 33.3% spent fixated on the Schedule 40 Tables. Greg's total fixations on each of the CRs indicates that they might have spent some time evaluating each CR before selecting one. The Headloss Chart has the highest percent and is considered the preferred CR to solve the problem based on the eye tracking data. However, during Greg's interview they indicate that they actually used the Schedule 40 Tables to solve the problem. When asked about their switch from the Headloss Chart to the Schedule 40 Tables, Greg uses two rationales, *Simplicity* and *Speed*, to explain why: "the more I understood what I was looking at on the [Schedule 40 Tables], the more I leaned towards something that made it simpler to solve."

The word "simpler" describes Greg's rationale for *Simplicity*. Greg further rationalizes their use of the Schedule 40 Tables when describing their experience as an engineering practitioner: "Experience has taught me that I need to find quicker, easier methods, and if someone's already calced it out for me, should probably follow that." The phrase "quicker, easier methods" describes the need to use a CR that requires both *Speed* and *Simplicity*. The combination of the two data sets clarified how Greg engaged with each context. The eye tracking data showed that

Greg spent more time referring to Headloss Chart but based on the interview data, Greg used the Schedule 40 Tables to solve the problem.

Angela

Angela referred to the Schedule 40 Tables most often when solving the problem, fixating 92.8% of their time to this CR. The eye tracking data also shows that Angela did not spend much time referring to other CRs besides the Schedule 40 Tables as the next greatest fixation percentage is 5.8% spent on Hazen Williams, with 1% or less spent referring to the Headloss Chart and Darcy Weisbach. With very little time spent fixated on the other CRs, the eye tracking data indicates that Angela did not spend much time evaluating other CRs. Based on the eye tracking data, the Schedule 40 Tables are the preferred choice for solving the problem.

During Angela's interview they used three different rationales for their choice of the Schedule 40 Tables. When asked how prior experience and intuition guided them through the solution process they said, "I've used that approach many, many times." This claim suggests that *Familiarity* is a factor when choosing a CR. Angela further described their reasons for choosing the Schedule 40 Tables as opposed to the other CRs: "Under this context, it would. If it were accuracy or I was programming something for variability, I would use the equation." This excerpt describes Angela's decision to choose the Schedule 40 Tables based on some additional understanding of the other CRs and they make their decision on the needs of the problem. This suggests Angela is using *Accuracy* to decide on what CR is suited for this problem.

Angela additionally describes their use of the Schedule 40 tables as providing a faster way of getting a solution, relying on the rationale for *Speed*: "I've used the [Hazen Williams] equation before if I have a spreadsheet, but I wouldn't necessarily do that if I had the tables and I was trying to do it fast."Angela also indicated their familiarity with the Hazen Williams equation which agrees with the eye tracking data. Angela's problem-solving process is unique in that they fixate very little on other CRs and base their process on the context of the problem-solving interview.

Brandon

Brandon referred to Darcy Weisbach more often during the problem, spending 47.3% fixated on this CR. Brandon also spent additional time referring to other CRs with 24.0%, 17.6%, and 11.1%, spent referring to the Hazen Williams, Headloss Chart, and the Schedule 40 Tables, respectively. Brandon's total fixations of at least 10% on each of the CRs indicates they spent some time evaluating each CR, which is similar to Greg's approach.

While Brandon fixated more on the Darcy Weisbach equation than the other CRs, they indicated in their interview that they used the Hazan Williams equation to solve the problem. During the interviews, Brandon describes the rationale of *Simplicity* when switching from the Darcy Weisbach equation to the Hazen Williams equation. Brandon makes this decision based on the recollection that Darcy Weisbach would require an iterative process: "So, having remembered that, I moved on to the Hazen-Williams, and I did remember that it's supposed to be easier to use in that regard. You just look for your C coefficient, and the rest of the variables are plug and play."

Their use of the word “easier” describes their choice to switch CRs to require *Simplicity*. The phrase “plug and play” also describing something that requires little effort to complete. Similar to Greg’s problem-solving process, Brandon’s switches CRs which is elaborated on in the interview. Brandon also uses the same rationale as Greg when moving from one CR to another, but Brandon ends up using a different CR than Greg to solve the problem.

Megan

Megan also referred most to Darcy Weisbach to solve the problem, fixating 65.8% of their time. The eye tracking data shows that Megan spent some additional time referring to the Schedule 40 Tables, 27.4%, with less time spent referring to Hazen Williams, 6.7%, and the Headloss Chart, .1%. The eye tracking data suggests that Megan preferred the Darcy Weisbach equation to solve the problem compared to the other CRs. Megan’s low fixation percentage on the Headloss Chart suggests this CR was only quickly referred to.

During the interviews, Megan relies on the rationales of *Simplicity* and *Familiarity* when describing why they used the Darcy Weisbach equation. Megan uses the rationale *Simplicity* when referring to Darcy Weisbach: “Yeah. [Darcy Weisbach] was definitely ... it was an easy equation that had all the exponents, so it's pretty straightforward in my opinion.”

Megan’s use of the phrase “easy equation” describes their personal experience with Darcy Weisbach as requiring less effort. This is further described with the phrase “pretty straightforward” implying that the use of the Darcy Weisbach likely requires less work and is simpler to use. When asked why they remained using the Darcy Weisbach equation even after referring to the Schedule 40 Tables, Megan relies on *Familiarity*: “Maybe just comfort? I'm not ... I guess the [Schedule 40 Tables], those ... that's kind of a foreign concept I guess. I know what they're saying, and I understand them, but I've never really ... I don't use them a whole lot.”

Megan’s use of the word “comfort” and describing the Schedule 40 Tables as unfamiliar aligns well with the rationale of *Familiarity*. This also corroborates the fixation percentages from the eye tracking data. Much like Greg and Brandon, Megan attempts to switch CRs but returns to their first choice based on the rationale *Familiarity*.

Discussion

Participants in this study used multiple CRs and often provided more than one rationale for their decisions during problem solving. The use of eye tracking data with retrospective interviews created a more robust set of interview questions that provided additional detail about the problem-solving process that would have otherwise been unaddressed. Each participant engaged with the CRs differently and had unique ways of problem solving. For example, some seemed to spend time looking at all representations before deciding, whereas others looked to identify a useful representation and move through the problem-solving process without returning to alternate representations. In-vivo codes were created to describe rationales based on the retrospective interviews. These rationales coincided with decisions during the problem-solving process that the eye tracking data corroborated. The rationales varied between each engineering practitioner and the CRs. These rationales describe why particular decisions are made during the problem-solving process.

Each of the CRs are inherently different from each other and require a different approach during the problem-solving process. Similar to previous research, engineering practitioners in this study were capable of navigating between each of the representations to solve the problem (Jonassen, Strobel, & Lee, 2006). However, when solving the problem, the engineering practitioners would often use the same rationale to describe their engagement with the CRs. This occurred with the use of *Familiarity*, *Speed*, and *Simplicity*. For example, when referring to the Darcy Weisbach equation, engineering practitioners use the rationale *Simplicity*. The mention of *Simplicity* suggests that perhaps there is something about the Darcy Weisbach equation that is simpler than the other CRs. However, *Simplicity* is also mentioned when using the Schedule 40 Tables. As the results show, multiple mentions of rationales also occurs with other rationales and CRs. This suggests that the rationale's meanings are not necessarily consistent across individuals. Greg's meaning of *Simplicity* is different from Brandon's and Megan's meaning of *Simplicity*. Nonetheless, they justify their use of different CRs with the same rationale. As the data from the remaining participants not focused on in this paper is analyzed, it is expected that additional patterns will emerge. Rationales like *Simplicity* and *Speed* appear to be related, however the preliminary results are not conclusive enough to make this determination.

Similar to previous research, this study showed that familiarity, much like experiential knowledge, is important in solving problems (Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007; Hurwitz, Brown, Islam, Daratha, & Kyte, 2014; Jonassen, Strobel, & Lee, 2006). *Familiarity* is used by two of the engineering practitioners as a description for their engagement with a CR. Moreover, past experience is also related to Greg's decision to search out "quicker, easier methods", which aligns with rationales *Speed* and *Simplicity*. This suggests that the rationales are related to an engineering practitioners' past experience and may be used during problem solving to determine what decisions an engineering practitioner will make. Expert and novice comparisons are often made in problem-solving research and have shown that engineering practitioners make different decisions during the problem-solving process. However, the rationale for these particular decisions within the problem-solving process of a practitioner is not fully understood. If an engineering practitioner bases their decisions on a particular rationale, understanding this rationale and how it is applied is an important aspect of the problem solving process. Combining the results from this study with previous research will lead to a holistic understanding of the problem solving-process.

Based on the results from this study, the compatibility of eye tracking and interview methods agrees with past research (Guan et al. 2006, Cook, Wiebe, & Carter, 2008; Patrick, Carter, & Wiebe, 2005; Stieff, Hegarty, & Deslongchamps, 2011). These two methods complement and support each other to describe more about the problem-solving process than either alone. The eye tracking data presented results on each of the engineering practitioners engagement with the CRs, highlighting unique features about each problem-solving approach. At the same time, the interview data provided a narrative to describe the engagement of CRs based on the eye tracking data. The combined data sets further clarified the engineering practitioners' thought processes and explained how some CRs with more fixations were not necessarily the preferred choice.

Implications and Future Work

Understanding the rationale of engineering practitioners during problem solving leads to some interesting implications. Rationale inflluences an engineering practitioners' approach to the problem, which affects the decisions, methods, and overall solution. This implies that the rationale of an engineering practitioner is an important factor when solving a problem. Therefore, understanding more about the rationale of practitioner problem solvers could influence the way problem solving is approached in an academic setting. By modeling these behaviors, rationale could be explained to engineering students in ways that develop additional methods to approach problem solving. Prior research has not focused on the rationale in problem solving and to understand how it is important to engineering practitioners, studying engineers, and faculty, requires more research on this topic.

Another area in need of further exploration is the links between quantitative eye tracking and qualitative interviews. The use of eye tracking during problem solving allowed the retrospective interviews to be supplemented with additional probing questions. These questions addressed specific actions made by the engineering practitioners, prompting them to provide richer descriptions for their decisions during problem solving. This interviewing method assisted in the development of the rationales by allowing the researcher to point out specific instances where an engineering practitioner moved from one CR to another. Moreover, the validity of the retrospective interview responses increased due to the eye tracking data. Each time a participant described their approach, the eye tracking data provided triangulation and allowed the researcher to further guide the participant through their own solution process. If a participant spent the majority of their time referring to a particular CR, the researcher was able to understand why that CR was important and also determine whether that CR was actually the preferred choice for solving the problem. But each data set only describes part of the problem-solving process. Future work will benefit through the combination of these two methods to gain a more complete and detailed depiction of the problem-solving process.

Further exploring the compatibility of these two methods could help to understand more about problem-solving decisions. The eye tracking data is capable of providing a timeline for problem-solving decisions. This is similar to Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007, where determining time spent in different stages of design created an interesting description of the overall process. Each stage of design was timed and this showed how experts allocated their time during the design process, allowing the researchers to compare these results to novices (Atman, Adams, Cardella, Turns, Mosborg, & Saleem, 2007). With the use of eye tracking, future work could look at each individual reference to a representation, information, or other problem-solving step and provide a detailed timeline of problem-solving events. Combining this method with retrospective interviews would additionally supplement that solution process and allow researchers to explore additional features of problem-solving behavior.

Future work could also be focused on the importance of rationale in varying contexts. This study was confined to an academic set of problems that did not represent a truly authentic workplace problem-solving experience for the engineering practitioners. By expanding this study to incorporate more authentic problem-solving experiences in varying workplace contexts, we may gain a better understanding of the problem-solving approaches of workplace problems.

The preliminary findings we have presented are a small sample of the data set and analysis to be completed. Additional participants and problems will be analyzed to help supplement our understanding of rationale and the overall problem-solving process of practitioners. The four participants studied in this paper demonstrated a wide range of responses and rationale and it is anticipated that as the sample size increases patterns and further conclusions are expected to emerge. We are also in process of collecting data for undergraduate students with the aim to provide a better understanding of student rationale in problem solving. By combining these two data sets, we will also complete a comparative analysis of student and practitioner problem-solving behavior associated with rationale.

Conclusion

The preliminary results of this study highlight the importance of rationale and how it can influence the problem-solving process of engineering practioners. Discovering more about the problem-solving process of engineering practitioners provides more information for educators and can impact how the problem-solving process is holistically understood. Eye tracking techniques supplemented and guided semi-structured interviews to discover more about expert rationale during the problem-solving process. The results show that engineering practitioners use multiple contextual representations and describe their problem-solving decisions with similar and varied rationales. This study contributes to previous problem-solving research by uncovering the rationales used in problem solving that assist in the understanding of *what*, *how*, and *why* decisions in problem solving are made.

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