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Problem Solving Personas of Civil Engineering Practitioners Using Eye Tracking Techniques*

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Engineering practitioners solve problems in various ways; it is plausible that they often rely on graphs, figures, formulas and other representations to reach a solution. How and why engineering practitioners use representations to solve problems can characterize certain problem-solving behaviors, which can be used to determine particular types of problem solvers. The purpose of this research was to determine the relationship between time spent referring to various representations and the justifications for the decisions made during the problem-solving process of engineering practitioners. A persona-based approach was used to characterize the problem-solving behavior of 16 engineering practitioners. Utilizing eye tracking and retrospective interview techniques, the problem-solving process of engineering practitioners was explored. Three unique problem-solver personas were developed that describe the behaviors of engineering practitioners; a *committed* problem solver, an *evaluative* problem, and an *indecisive* problem solver. The three personas suggest that there are different types of engineering practitioner problem solvers. This study contributes to engineering education research by expanding on problem-solving research to look for reasons *why* decisions are made during the problem-solving process. Understanding more about how the differences between problem solvers affect the way they approach a problem and engage with the material presents a more holistic view of the problem-solving process of engineering practitioners.

Keywords: problem solving; personas; eye tracking; retrospective interview

1. Introduction

Problem solving is a common activity for practicing engineers. No matter the size of the project or design, problem solving often leads to specific recommendations that an engineering practitioner will make to meet the needs of their client. During the problem-solving process, engineering practitioners may engage with a wide variety of data, representations, contexts, and people. How engineering practitioners and students determine a solution has been an important focus of engineering education research [1–4]. These studies have explored how engineering students' learning or performance is affected by trying to mimic a more authentic engineering experience or workplace context. These studies show that engineering students typically become better equipped for engineering practice and the workplace following the implementation of these interventions. However, little research discusses the specific characteristics of engineering practitioner problem solvers and their behavior. Understanding more about the types of engineering practitioner problem solvers further explains their behaviors and offers new insight into their decision-making processes. To address this gap, this research focused on *how* and *why* engineers make decisions during the problem-solving process through monitoring and interviewing engineering practitioners as they solved problems.

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2. Literature review

2.1 Problem solving research

Prior engineering education research has focused on many aspects of the problem-solving process. This research has predominately focused on the *how* and *what* of problem-solving behavior. Jonassen, Strobel, and Lee discussed the attributes of workplace problems with engineering practitioners and how context, activities, and constraints contribute to the ill-structured nature of workplace problems [2]. The authors discuss how the success of engineering practitioners primarily relies on their experiential knowledge and capability of using multiple forms of representations to solve a problem [2]. Comparisons have also been made between novices and expert practitioners to show that expert practitioners tend to spend more time gathering information, considering alternatives, and designing [1]. A bulk of problem-solving research focuses on student problem-solving behaviors. This includes student application and engagement with representations [5–8], textbook utilization [9], the introduction of authentic real-world problems such as model eliciting activities (MEAs) [10], and the introduction of other kinds of problem-based learning strategies

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[11–13]. However, research on the problem solving of engineering practitioners is under-explored.

One of the most common and important activities engineering practitioners do is solve problems. The problems vary in size and complexity and may lead to a new design, retrofit, or to a solution for a more complex world problem. Engineering practitioners will likely interact with multiple representations to reach a solution. Representations can take many forms including tables, graphs, figures, spreadsheets, formulas, images, charts, visualizations, and other material that represent a concept or material context that can be used to solve a problem. Representations assist in problem solving by organizing important conceptual information which can assist with the cognitive load experienced by the problem solver [14]. One way to better understand a problem-solver's behavior is by studying how they engage with representations.

2.2 *Representation in problem solving*

Significant research has been devoted to the understanding of representations in problem solving, lending many names and definitions for the representations such as discipline specific representations, expert generated representations [7], multiple external representations [15], contextual representations [16], textual, diagrammatic, or symbolic representations [17], or verbal representations [18]. Each representation can be thought of as a means to solve the problem *and* an engineering practitioner will rely on one or more of these representations for information to reach a solution. Prior research has shown that the type of representation (i.e. graphical, formula, figure) has an effect on which representation will be used during problem solving [18–21]. Through interaction with a representation and the reasons given for using it, we can learn more about problem-solving behavior.

Continuous interaction with representations can lead to a type of fluency, much like the learning of a new language. Previous research has highlighted the importance of representational fluency, showing that as a problem solver becomes more fluent in the representations, they tend to take advantage of multiple representational forms to make meaning, solve problems, and communicate within a domain [7]. Representational fluency also leads to an increase in the overall quality of their solution or design [7, 22, 23]. Representational fluency has been described as representational competence and metarepresentational competence. Representational competence encompasses a set of skills that includes "constructing, interpreting, transforming and coordinating domain-specific external representations" [8], [20, 22, 24, 25]. Metarepresentational competence describes an individual's ability to better understand the justification behind a representation [7] which can lead to their ability to determine which representation is most appropriate [26]. Previous studies have shown that expert chemists and physicists exhibit higher representational fluency when compared to novices. These experts were shown to sort representations based on conceptual features rather than surface features [24] and were also found to solve problems faster and move more quickly amongst representations [27]. Conceptual features are related to the principles and concepts of a representation and are typically not apparent when looking at a representation. Concepts include the types molecular interactions, physical laws, and other features and interactions that may not be visible when looking at the representation [24]. Surface features are the physical features of a representation that could include color, shape, whether the representation is a graph or an equation, or the symbols used to represent particular variables and terms [24]. Representational fluency research has often focused on students or the comparison between novices and experts in math and scientific domains such as physics and chemistry [8, 24, 27, 28]. Limited research exists on the representational fluency of practitioners, specifically in the field of engineering. Our research does not aim to understand engineering practitioner's representational fluency in problem solving instead we have looked at this research because of the similarities between the use of representations and representational fluency. There is a need to extend the use and development of representations to students to improve their understanding of the principles and concepts of representations [7, 20, 23, 27, 29]. This need can be met through better understanding *how* and *why* experts and practitioners use different representations.

2.3 *Problem solving heuristics*

Previous research has shown that many forms of problem-solving heuristics are employed during the problem-solving process. A heuristic is commonly described as a rule that assists a problem solver to a solution. These rules often create a shortcut for the problem solver that help them form judgments and make decisions [30]. Problem solving heuristics can be a formal step by step process for solving a problem [31], or a way to describe a solution approach such as a means-end-analysis [32], or schema application [15, 27, 33]. When presenting a problem solver more than one representation as an approach to solve a problem, they have to decide which approach they prefer or is best suited for the problem. We consider this decision to be associated with a heuristic or justification for their solution approach. Outside of minimal anecdotal evidence in problem-solving research, there is little mention of the justification for *why* problem-solving decisions are made [20]. Revealing the justifications engineering practitioners use will provide additional detail about the problem-solving characteristics and behaviors of problem solvers.

2.4 Eye tracking and interviewing techniques

Research on problem solver behavior has been done with multiple quantitative and qualitative techniques. It is common for the two techniques to be combined to provide a robust story of the problem-solving process. Independently, quantitative methods typically provide a data set that speaks to the *what* of problem-solver behavior. Through the use of either video recording or eye tracking techniques a problem solver's actions can be monitored and time spent with particular tasks or features of a problem, such as representations, can be quantified [1, 4, 20, 23, 25, 34–37]. When coupled with interview techniques, the qualitative data begins to describe more about the *how* and starts to point towards *why*. Previous research has combined interviewing techniques such as think-aloud, clinical, and retrospective with audio and video recording, as well as eye tracking techniques [1, 20, 38–40].

Eye tracking equipment is capable of collecting data on the fixations which can be used to understand more about the problem-solving process. A fixation is defined as a visual gaze on a region of the screen for more than a 10th of a second. Just and Carpenter (1980), presented the eye-mind assumption that suggests that eye movements are correlated with focus and cognitive processing [41, 42]. Eye tracking data provides a unique way to quantify eye glance patterns which can be used to characterize certain behaviors during the problem-solving process. By relying on the relationship between fixations and cognitive processing, assumptions about engineering practitioner problem-solving behavior can be made using the total time spent fixating on particular representations during problem solving [41]. Interview data enables confirmation of this eye-mind assumption and allows for a more robust description of the problem solver's decision making.

Previous research has primarily focused on student engagement with representations during problem solving. Using both eye tracking and interviewing techniques, Stieff et al. (2011) studied the use of molecular representations amongst college students to compare time spent referring to individual representations. Their research discovered that students preferred visual and graphical representations over conceptually equivalent equations and that a student's performance was related to which representations they used and their ability to integrate multiple representations at once [20]. Similar problem-solving research using both eye tracking and interviewing techniques was done with middle and high school students to determine the important features and student comprehension of multiple molecular representations [38, 39]. Each of these studies combined eye tracking and interview techniques to understand *what* and *how* representations were used amongst students. These studies did not focus on the problem-solving decisions that are associated with *why* a representation was used.

Limited research exists with experts from any science related domain that incorporates eye tracking techniques, specifically in engineering related fields. Eye tracking and interview methods have been used to understand how expertise is related to glance patterns using dynamic and static representations [34, 43]. When studying the effects of expertise on the perception and interpretation of dynamic representations of fish locomotion, biology experts were shown to attend more to relevant aspects and use more heterogenous task approaches and knowledge-based shortcuts when compared to novices [43]. Additionally, when troubleshooting electrical circuits, experts spent more time and fixated more on major fault-related components during multiple stages of the troubleshooting problem [34]. This means that experts tend to have different fixation patterns that are related to their performance analyzing both dynamic and static representations. These studies highlight the importance of understanding expert problem-solving behavior associated with their interaction with representations. Prior research has not focused on the fixations between multiple representations and how experts behave during problem-solving scenarios.

To date, the reasons behind a practicing engineer's problem-solving decisions and how they interact with representations is under researched. Research in problem solving with experts and practitioners has shown that there are unique approaches to problem solving. Variations of time spent with particular tasks, fixating on representations, and solving a problem provide details about the characteristics of problem solvers. Interviewing techniques have helped to further explain these results but there is much to be discovered about the reasons associated with problem-solving decisions. One way to begin addressing this gap in the research is through the use of abstract problem-solver personas.

2.5 Personas

We define a persona as the behaviors, characteristics and goals of an individual and how that relates and contrasts with other individuals. Carl Jung first proposed the idea of a persona as the "socially acceptable face of the individual or group" [44]. Personas have been used in previous research to understand the characteristics of engineering innovators [45] and the needs and behaviors of requirements engineers [46], [47]. A persona is often used in marketing to create character profiles for a target consumer population [48]. Personas provide the ability to create one profile of a fictitious person based on the aggregation of real peoples' salient behaviors that allow an interested party the ability to efficiently understand an entire group of people [46–49].

Persona research has also been used to describe the traits and beliefs of engineers and engineering faculty. In engineering education, qualitative research including the analysis of interviews using themes presented three unique personas to discuss the relationship of civil engineering faculty beliefs about sustainability and the actual practice of integrating sustainability in their classrooms [50]. By categorizing the characteristics of engineering innovators, Ferguson used 10 unique personas as a means to show how engineering innovators displayed "unique knowledge, skills, and attributes that they use to support the creation, development, and implementation of the innovations with which they are involved" [45]. The development of personas based on engineering innovativeness and sustainability beliefs allowed for the comparison across groups of people based on their traits and beliefs.

We used personas to categorize important problem-solving traits of engineering practitioners to address the gap in understanding *why* decisions are made during the problem-solving process. The combination of eye tracking and retrospective interview techniques provided a robust picture of the problem-solving behavior of engineering practitioners. Maxwell (2010) discussed the benefits of using quantitative data to compliment qualitative research by allowing individuals to see larger patterns and to develop a "clearer and more in-depth understanding" of the data [51]. Simply categorizing the quantitative eye tracking data would not have provided enough insight of the types of problem solvers and their decision processes. To more accurately portray the practitioner problem solver personas, their real words are presented. These personas will shed light on important traits that could be used as models of problem solving and in various instructional methods.

Research in engineering education has highlighted the importance of understanding workplace problems and contexts, and engineering practitioner decision making. There is a continuous need to complete research on engineering practitioners to advance our understanding of their problem-solving behavior. Research with students has shown that their use of representations varies depending on experience, which suggests that there is more to learn about the representational use of more experienced problem solvers and what this could say about their problem-solving behavior. Our research describes the problem-solving behavior of engineering practitioners by investigating *how*, *what*, and *why* they use multiple representations. Understanding the relationship between these problem-solving characteristics can help discover unique types of engineering practitioner problem solvers.

2.6 Research goal

The goal of this research was to establish a relationship between time spent referring to and the justification for using a representation for engineering practitioners during problem solving. Our goal was addressed by developing problem-solver personas based on the characteristics and behaviors of engineering practitioners. These behaviors are based on how much time engineering practitioners spent referring to different representations during problem solving and the reasons engineering practitioners give for their selection of a given representation.

3. Methods

We developed relevant problems focused on the concept of headloss in pipe flow to determine the problem-solving behaviors of engineering practitioners that would lead to problem-solver personas. Each problem included four representations relevant to civil engineering practitioners that are commonly used as a means to solve the problem. Engineering practitioners participated in a problem-solving interview where they wore eye tracking glasses that tracked their eye movements as they solved three problems. Following the problem-solving interview, engineering practitioners completed a retrospective interview to further discuss their thought process and reasoning during problem solving. This section describes the development of the problem-solving interviews, participant selection, and the data collection and analysis. This analysis is part of a larger project to understand problem solver behavior across multiple problems and to provide a comparative analysis of novices and experts. We describe the methods to develop the entire problem set; however, only the results from one problem are presented herein.

3.1 Problem-solving interview development

The problem-solving interviews are separated into two parts. The first part includes the solving of three problems while being monitored using eye tracking

Table 1. Description of the four representations provided to solve each problem

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	Tripartite graph	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.

techniques. The second part is a retrospective interview conducted immediately following the problem-solving portion of the interview. This section will describe the problem development, retrospective interview development, and beta testing of the entire interview. The problem and the four representations used in this study are presented in Figs. 1a and 1b.

3.1.1 Problem development

Our problems were developed using the details from informational interviews with practicing engineers. We conducted six informational interviews with civil engineering practitioners who focus on the hydraulic design of pipe systems. The interviews were semi-structured and conducted over the phone with engineering practitioners from firms in the greater Portland, Oregon area following qualitative research techniques [52]. These interviews provided insight on the engineering concepts, reference material, representations, and types of problems relevant to engineering practitioners.

Problems were designed with a relevant number of representations that could be used to solve the problems. The most salient engineering concept from these interviews was headloss in pipes. The most common representations mentioned were the Darcy Weisbach and Hazen Williams formulas, headloss tables based on pipe type, and figures and charts from pipe manufacturers. Problem descriptions provided during the informational interviews agree with previous research that the types of problems engineering practitioners solve are typically open-ended and ill-structured design problems [2]. These problems require multiple steps and usually involve numerous concepts and representations. We designed a simpler set of single concept problems focused on headloss in pipes due to the complex nature of workplace problems.

Eight problems focused on headloss in pipes were initially created using the informational interviews and academic reference material. As previously mentioned, this study is part of a larger study that will also focus on the problem-solving behavior of engineering practitioners who are exposed to different problem formats. Therefore, the eight problems were created in multiple problem formats that included, ranking, multiple choice, and open-ended. For this study, we will analyze only the data from the open-ended format problem because it is the most relevant to the problems engineering practitioners solve.

The four representations present the concept for the calculation of headloss in a pipe and include two equations, a set of tables, and one figure. These representations were chosen from the informational interviews with practicing engineers and the review of academic textbooks and reference material. Each of the four representations are summarized in Table 1. Practitioner preference guided the selection and application of a particular representation to solve the problem.

Each problem and the four representations were combined into eight single slides in PowerPoint to be used during the problem-solving interview. The slides provided a presentation of the problem statement and the four representations. It was important to create boundaries for the problem statement and the four representations to facilitate the use of the eye tracking equipment by making specific areas of interest easy to distinguish. The slide for the first problem that will be analyzed in this study is shown in Figs. 1a and 1b.

3.1.2 Retrospective interview development

The goals of the retrospective interview were to determine which representation was used and why, understand how each practitioner solved each problem, learn more about how each of the representations were relevant to the practitioners' current work, and discover what other representations or material may be relevant to their current work. An 11-question semi-structured interview protocol was designed to meet these goals. Due to the unique nature of each practitioner's problem-solving approach, the semi-structured interviews provided

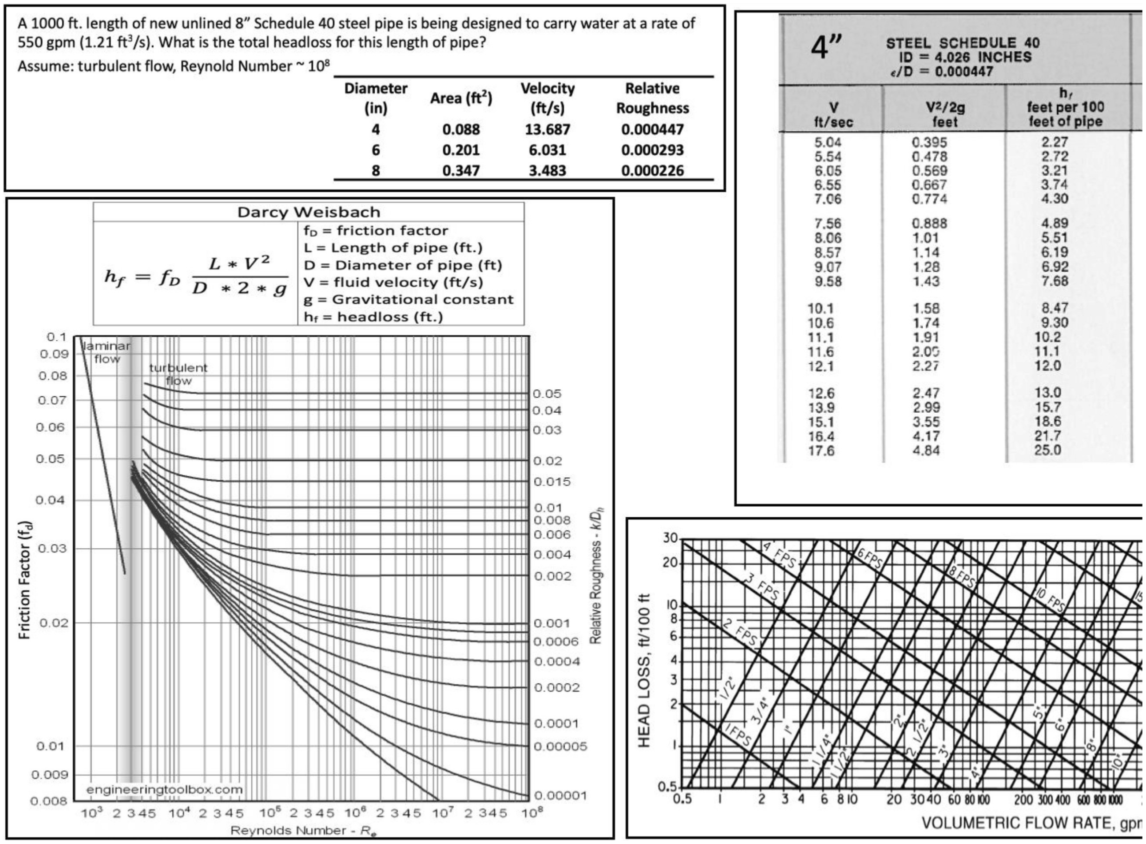


Fig. 1a. First half of the problem slide for the first problem that is analyzed in this study.

a means to outline the interview but remain flexible so that details specific to each participant could be collected. This flexibility comes from the ability to include probing questions inspired by the engineering practitioners' problem-solving approach and their answers to the pre-developed questions.

3.1.3 Beta testing the problem-solving interviews

Two beta tests were completed with the problem-solving interview with two civil engineering graduate students. Participants for the beta test were selected based on their experience with the concept of headloss and problem solving. The two beta tests yielded that eight problems would require up to two hours to solve. We reduced the number of problems to keep the entire problem-solving and retrospective interview under one hour. Three problems from the eight were selected that were unique and required the most use of the representations provided. Additional edits included minor formatting changes to the problem slides to improve visibility and to improve the collection of the eye glance patterns. Additionally, it was noted that real time monitoring of the glance patterns during the problem-solving interview improved the quality of the probing questions during the retrospective interview and led to a more robust narrative for the problem-solving process.

3.2 Participants

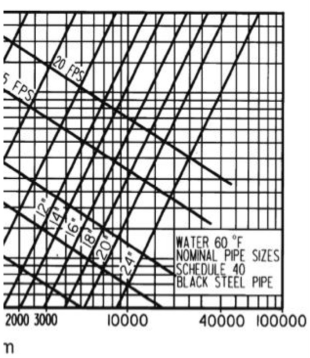
We recruited practitioners from the civil engineering industry who worked with pipe design to gain an authentic understanding of practitioner problem solving behavior. We preferred practitioners to interact with the concept of headloss while in the workplace. Convenience and snowball sampling was used to recruit the practitioners from public and private offices in the greater Portland, Oregon area to produce a large enough data set of civil engineering practitioners with relevant experience [53]. Convenience sampling allows for a purposeful selection of practitioners while snowball sampling assists in gathering a larger data set. The snowball sampling relied on practitioners to forward a recruiting announcement of our study to additional engineering practitioners. Interviews were completed until we reached saturation of the practitioner data [54]. Saturation was reached once no new evidence for unique findings were uncovered in the interviews and we established an acceptable level

6″ STEEL SCHEDULE 40
ID = 6.065 INCHES
ϵ/D = 0.000293

V ft/sec	$V^2/2g$ feet	h_f feet per 100 feet of pipe
1.11	0.0192	0.0843
1.33	0.0276	0.118
1.55	0.0376	0.155
1.78	0.0491	0.198
2.00	0.0621	0.246
2.22	0.0767	0.299
2.44	0.0927	0.357
2.66	0.110	0.419
2.89	0.130	0.487
3.11	0.150	0.560
3.33	0.172	0.637
3.55	0.196	0.719
3.78	0.222	0.806
4.00	0.240	0.898
4.22	0.277	0.993
4.44	0.307	1.09
4.66	0.338	1.20
4.89	0.371	1.31
5.11	0.405	1.42
5.33	0.442	1.54
5.55	0.479	1.66
6.11	0.580	1.99
6.66	0.690	2.34
7.22	0.810	2.73

8″ STEEL SCHEDULE 40
ID = 7.981 INCHES
ϵ/D = 0.000226

V ft/sec	$V^2/2g$ feet	h_f feet per 100 feet of pipe
1.03	0.0164	0.0521
1.15	0.0207	0.0644
1.28	0.0256	0.0780
1.41	0.0309	0.0928
1.54	0.0368	0.1088
1.67	0.0432	0.1260
1.80	0.0501	0.144
1.92	0.0575	0.163
2.05	0.0655	0.184
2.18	0.0739	0.206
2.31	0.0828	0.229
2.44	0.0923	0.253
2.57	0.102	0.279
2.89	0.129	0.348
3.21	0.160	0.424
3.53	0.193	0.507
3.85	0.230	0.597
4.17	0.271	0.694
4.49	0.313	0.797
4.81	0.360	0.907
5.13	0.409	1.02
5.45	0.462	1.147
5.77	0.518	1.27
6.09	0.577	1.41
6.41	0.639	1.56
7.05	0.773	1.87



Hazen Williams

$$h_f = \frac{10.44 * L * Q^{1.85}}{C^{1.85} * D^{4.8655}}$$

C = Hazen Williams Coefficient
L = Length of pipe (ft.)
D = Diameter of pipe (in.)
Q = Flow Rate (gpm)
h_f = headloss (ft.)

Pipe Material	Recommended C Value	
	New Pipes[@]	Design Purpose
Unlined Metallic Pipes		
Cast Iron, Ductile Iron	130	100
Mild Steel	140	100
Galvanized Iron above 50 mm dia. #	120	100
Galvanized Iron 50 mm dia and below used for house service connections. #	120	55

Fig. 1b. Second half of the problem slide for the first problem that is analyzed in this study.

of generalizability between practitioner problem solving experiences [54].

Data for 28 participating engineers were collected, evaluated and refined based on the eye tracking data and retrospective interview questions. Participation was voluntary, but participants were offered compensation. Engineers were compensated $20 for the hour-long interview. Of those 28 practitioners, eye tracking data for 6 practitioners was determined to be unreliable due to data corruption or because the interviewee bumped the eye tracking glasses during the interview, disrupting the equipment calibration. Sixteen of the remaining 22 practitioners were selected based on their relevant workplace experience with the concept of headloss. The decision to remove the additional 6 practitioners came after the analysis of the retrospective interviews. Although all our participants worked in the civil engineering industry, it was evident from the retrospective interviews that some of the practitioners lacked relevant workplace experience related to headloss in pipes.

For the 16 practitioners, workplace experience ranges from 1 to 27 years with an average of 11.4 years. Seven practitioners were female (44%) and 9 practitioners were male (56%). The experience of the participants ranges from engineering technicians to design team managers. Participants work in pipe design for sewer, stormwater, and potable water systems that are both gravity and pump fed.

Prior research employing eye tracking or similar techniques with interviews while problem solving rely on an average data set of 18 participants [1, 20, 27, 37, 39, 55]. Prior research on persona development can range substantially depending on the methods used to collect data. Data sets for persona research utilizing interviews ranged between 18 and 46 participants [45, 50]. Our data set is typical of research incorporating eye tracking and persona methods. The combination of eye tracking and interview data produces a robust sample for the data analysis. The personal problem-solving experiences of engineering practitioners provide a rich description of their behaviors. Additionally, combining these methods results in comprehensive data for each participant and additional complexities in analysis, further justifying a sample of 16.

3.3 Data collection

Data collection for the problem-solving interviews resulted in two data sets. The first data set includes the glance patterns collected during problem solving and the second data set are the transcripts from the retrospective interviews. This section describes how the eye tracking data for glance patterns was collected while problem-solving and how the retrospective interview data was collected following the problem solving.

3.3.1 Eye tracking and problem solving

While solving problems, the engineering practitioners wore eye tracking glasses. We used the Mobile Eye-XG platform from Applied Sciences Laboratories and ETAnalysis software from Argus Science to collect and analyze glance patterns. Engineering practitioners sat in front of a $25'' \times 10''$ monitor which displayed the problem slides. A calibration process for the eye tracking equipment was completed prior to each interview based on the specifications of the ETAnalysis software. This process ensured that the eye tracking glasses were reliably tracking the glance patterns of each practitioner. Each practitioner was provided blank sheets of paper to complete any hand calculations and were allowed to bring their own calculator. While solving the problems, the practitioners were allowed to ask any clarifying questions and per their volunteer involvement, they could skip a problem or leave the interview at any time.

3.3.2 Retrospective interviews

Immediately following the problem-solving portion of the interview, a retrospective interview was conducted. Using the developed retrospective interview protocol, Table 2, the practitioners answered questions that focused on their thought processes and reasoning during the problem-solving process. All interviews were audio recorded and transcribed by a 3rd party transcription service.

Additional probing questions designed to elicit more detailed responses were used throughout the interview that were tailored to the practitioners' responses as well as the real time monitoring of their eye glance patterns. Also, by monitoring the practitioners' eye tracking fixations in real time, we discovered that we were able to witness each time a practitioner glanced at a representation. We used this real time monitoring to generate specific questions that focused on the practitioners' actions during problem solving. This included times when the practitioners may have otherwise excluded details. For instance, to get the practitioner to discuss more details of their problem-solving approach we asked, "*Okay. So, it looked like you kind of went from the [Darcy] and then you kind of looked at those tables at the top there for a moment, and kind of went back to [Darcy]. What made you avoid sticking with those tables, and or using a different [approach] other than those two*?" This and other similar probing questions based on these observations contributed to a more robust narrative about the problem-solving process which included details that would have likely not been discussed.

3.4 Data analysis

The methods used to develop the personas required the analysis and interpretation of the eye tracking and retrospective interview data to understand the relationship between these two data sets. Each data set was analyzed thematically to determine independent themes for unique types of problem solvers. This section describes the analysis of each data set that led to three distinct problem-solver themes for each data set. The themes for each data set were compared and combined to produce three problem solver personas.

3.4.1 Eye tracking

The eye tracking data was manually reduced to determine the amount of time that each practitioner fixated on a particular representation. Each representation, the problem statement, and any glance off

Table 2. Questions used in the retrospective interview protocol

Retrospective Interview Questions
When looking back at your solution to problem 1, what made you choose the method you did?
Are you familiar with the contexts provided with problem 1?
How do these contexts relate to the work you do?
Why did you avoid the use of the other material contexts?
Is simplicity a factor when approaching these contexts?
What assumptions do you make outside of the stated assumptions to solve these problems? Why did you make those assumptions?
Walk us through the steps that you took to solve this problem and elaborate more on the reasoning behind each of the steps?
How did prior experience or intuition guide you through the solution process?
How confident are you with the answer you provided?
Are there additional resources you use or prefer to use to solve these problems?
How is the concept of headloss important to work you do?

the screen were considered an Area of Interest (AOI). The ETAnalysis software used glances within each AOI to calculate multiple visual variables that include fixation counts, percent total fixation durations, and total time. Fixations on the problem statement AOI and off the screen AOI were removed to create a comparative analysis between representations. To remove the effect of time spent fixating on the problem statement and off the screen, the percent total fixation durations (TFD) were recalculated for the four representations. The percent TFD provide a normalized set of data between all practitioners.

The eye tracking data for the total percent fixation durations of each participant is shown in Table 3. Using the percent TFD, the data shows how much time a practitioner refers to a representation relative to the other representations. These relative percentages describe how each practitioner divides their visual attention between each of the representations.

Table 3 shows each of the 16 practitioners' time spent fixating on each representation and the total time it took a practitioner to solve the problem. The value next to each representation's fixation time is the percentage of time spent fixated on that particular representation relative to the other representations. For example, practitioner 1 spent 5% of their time fixating on the Darcy Weisbach Formula, 52% on the Tripartite Graph, 10% on the Hazen Williams Formula, and 32% on the Headloss Tables. This would imply that they spent the majority of their time fixating on the Tripartite Graph and from this data it would be assumed that the Tripartite Graph is the preferred representation. Additionally, how the fixation percentages vary between each representation says something about the practitioner's problem-solving behavior. This table also includes the mean fixation times and total percent fixations durations for all 16 practitioners.

The mean fixation durations show that the most time spent and most total fixation percentage of the representations is on the Headloss Tables. The Darcy Weisbach Formula has the second highest average total time and average total fixation percentage but is still used 8% less often than the Headloss Tables. Both the Tripartite Graph and the Hazen Williams Formula are used for similar amounts of time, but vary in total average percent by 3%. Additionally, the Hazen Williams Formula has the lowest average total time and the lowest average fixation percentage. This means the Hazen Williams Formula was the least preferred representation out of the four representations. Table 3 also shows which practitioners solved the problem correctly. Problem correctness is not the focus of this study; however, it was used a means to compare representation use amongst practitioners.

Total time spent referring to a representation was used to characterize thresholds for the eye tracking data to define a type of problem solver. A visual analysis of the data was used with the goal of characterizing problem solvers based on the time they spent fixating on the representations. The data was graphed using bar charts to visualize how each practitioner allocated their time between representations. The bar charts were iteratively analyzed by observing themes in the engineering practitioners' total percent fixation durations that led to clusters. The initial observation of the bar charts indicated

Table 3. Total fixation durations, percentages, and total time for the 16 engineering practitioners

	Total Fixation Duration (seconds)					
Practitioner	**Darcy Weisbach Formula (%)[2]**	**Tripartite Graph (%)[2]**	**Hazen Williams Formula (%)[2]**	**Headloss Tables (%)[2]**	**Total Time[1]**	**Problem Correct**
1	4.68 (5)	46.54 (52)	9.28 (10)	29.11 (32)	316.81	Yes
2	97.5 (92)	1.49 (1)	1.31 (1)	5.59 (5)	203.82	No
3	26.58 (23)	19.44 (17)	4.07 (4)	65.42 (57)	312.63	Yes
4	9.5 (18)	6.66 (12)	4.48 (8)	33.5 (62)	111.41	Yes
5	49.3 (54)	3.5 (4)	3.71 (4)	34.2 (38)	124.88	No
6	1.75 (2)	1.17 (1)	37.19 (35)	66.53 (62)	195.28	Yes
7	8.98 (25)	0 (0)	0.65 (2)	26.5 (73)	85.33	Yes
8	3.35 (13)	0 (0)	19.46 (74)	3.56 (14)	76.25	Yes
9	22.03 (13)	79.25 (46)	12.67 (7)	56.94 (33)	379.91	No
10	10.46 (18)	20.02 (35)	1.84 (3)	25.24 (44)	164.7	No
11	20.58 (42)	0.81 (2)	25.51 (52)	2.53 (5)	162.25	No
12	54.68 (66)	0.1 (0)	5.56 (7)	22.76 (27)	222.11	No
13	58.07 (62)	1.38 (1)	2.17 (2)	31.99 (34)	232.6	Yes
14	11.91 (20)	2.22 (4)	19.01 (31)	27.48 (45)	176.4	Yes
15	15.71 (40)	1.1 (3)	2 (5)	20.46 (52)	174.53	Yes
16	0.41 (1)	0.13 (0)	2.3 (6)	36.76 (93)	152.36	Yes
Mean	24.72 (32)	11.49 (15)	9.45 (12)	30.54 (40)	193.20	–

Note. [1] This is the total time to solve the problem with all fixations including those outside of the 4 representations. [2] This is the percentage of total time spent fixating between the 4 representations exclusively.

that there were unique types of problem solvers. Practitioners typically spent most their time referring to one representation but how they divided their time between multiple representations varied. Based on this initial observation, we developed three main thresholds for the time spent with the practitioner's most used representation that included above 60% and 50%, and below 50%. Additional characterizations are summarized in Table 4. We consider these characterizations as the boundaries between problem-solving behavior that emphasizes the most important similarities and differences between problem solvers.

The first of the characterizations is all practitioners who spend 60% or more of their time fixating on one representation. Additionally, this practitioner typically spends less than 30% of their time on the second most used representation and less than 10% on their third. The least used representation is typically referred to approximately 1% of the time. This suggests that the practitioner relies heavily on one representation with little time spent fixating on other representations.

The second characterization is the practitioners who spend 50%–60% of their time with one representation and more than 30% of their time on their second most used representation. This practitioner also typically spends less than 10% on their third and approximately 3% on their fourth. This suggests that even though the practitioner relies on one representation, they typically spend some additional time with one or more other representations.

The third characterization is the practitioners who spend no more than 50% of their time fixating on one or more representation. Additionally, this practitioner spends more than 30% and 10% on their second and third most used representations and approximately 5% on their fourth. This suggests that the practitioner does not rely as much on only one representation and instead they distribute their fixation durations on multiple representations.

Table 4. Eye tracking characterizations for three types of practitioner problem solvers

Practitioner Characterization	Representations Ranked by Use[1] 1	2	3	4
1	>60%	<30%	<10%	~ 1%
2	>50%	>30%	<10%	~ 3%
3	<50%	>30%	>10%	~ 5%

Note. [1] The numbers 1–4 signify the first, second, third, and fourth most used representation for each practitioner.

3.4.2 Retrospective interview analysis

Thematic analysis of the interviews followed the guidelines and suggestions of common qualitative research approaches [52, 56, 57]. Transcripts from the retrospective interviews were analyzed in the online qualitative research tool Dedoose® [58]. Upon first review, we found the interviews to be in-depth accounts of engineering practitioner problem solving. We used the practitioners' own words when describing their reasoning for the use of a particular representation to preserve the ways practitioners describe their problem-solving behavior.

The retrospective interview data was characterized in Dedoose® [58] based on the details of the practitioners' problem-solving approach. Themes based on the narrative of each practitioner were used to characterize unique problem solvers. Two iterations of the retrospective interview data produced three unique characterizations. We identified the three characterizations using titles that we defined using our interpretation of the practitioner's own words. Each characterization title was chosen because we interpret the practitioners' descriptions of their problem-solving approach as *Committed*, *Evaluative*, or *Indecisive*. The first iteration looked for words describing which representations the practitioners used to determine how they solved the problem. This analysis led to the discovery of three groups of practitioners. This initial grouping is similar to the eye tracking characterizations which does not explain why the representations were chosen. A second iteration was necessary to learn more about the reasons behind the practitioners' problem-solving decisions and allow for further characterization of their behaviors. The three retrospective interview characterizations were compared to the independently created eye tracking characterizations, Table 5. This comparison suggests that there is correlation between the eye tracking and retrospective interview characterizations.

3.4.3 Persona development

Persona development relied on the characterization of the eye tracking and retrospective interview data

Table 5. Comparison of the characterizations for the two data sets

Characterization	One representation above 60%	One representation above 50%	All representations below 50%
Committed	6	0	0
Evaluative	2	5	0
Indecisive	0	0	3

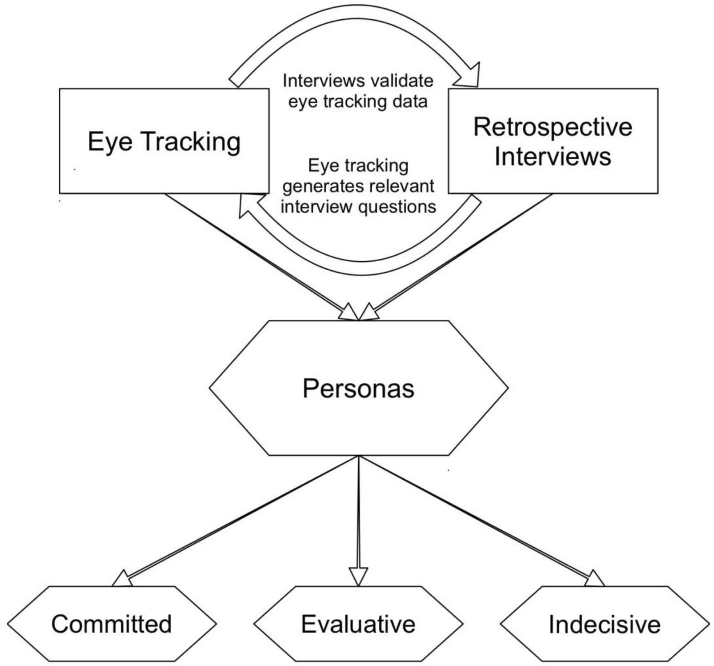


Fig. 2. A flowchart that represents a summary of the methods.

sets. We relied on a combination of sources to develop our problem-solver personas due to the lack of relevant guides for persona development in engineering problem-solving. Personas were developed based on previous research, qualitative research methodologies, and the persona development process outlined in *The Persona Lifecycle: Keeping People in Mind Throughout Product Design* [48, 50, 57, 59]. Our approach closely followed Adlin and Pruitt's (2010) 6-step process along with additional qualitative and quantitative research methodologies that led to the development of persona profiles that depict a unique type of problem solver. We relied on the independent characterization of each data set to determine the relationship between the two data sets leading to the development of three problem-solver personas.

Following Adlin and Pruitt's (2010) 6-step process, we used the characterizations as skeleton profiles to determine the problem solver personas. The skeleton profiles presented a rough outline of each persona. We looked for the uniqueness and differences between each characterization to ensure that we had definable boundaries between each profile. During group research meetings we prioritized the skeleton profiles to determine which problem-solving characteristics were most salient amongst the practitioners. We added data and individualized details based on the words of the practitioners to develop the profiles into personas. Quotes were extracted from the retrospective interviews that describe the most salient behaviors of the practitioners within a persona. The words of each practitioner within a persona are used as examples of that persona's behavior.

The problem solver personas rely on the characterizations of quantitative eye tracking and qualitative retrospective interview data. Combining these two data sets follows the suggestions from Maxwell (2010) in an attempt to more adequately present our interpretations of the data. In qualitative research studies, the researchers' interpretations of the data are the results. The findings are more characteristic of the setting or the individuals studied by using numerical data to complement those results. Supplementing the interview data with eye tracking data helps to remove biasness in our characterizations of problem-solver behaviors by presenting more evidence for our interpretations [51].

The methods of this paper relied on the synergistic interaction between the eye tracking and retrospective interview data sets. A summary of the methods is presented in Fig. 2 as a flowchart that simplifies the iterative process to produce the problem-solver personas. Persona development relied on the combination of the characterizations of the two data sets. The three problem solver personas are presented in the following Results section.

4. Results

The results are presented as three problem-solver persona profiles that depict three unique character-

Table 6. Persona summary table

Persona	Persona Definition	Persona Goals
Persona 1 6 practitioners	*Committed:* This practitioner relies mainly on one representation and can be described as confident in the representations or stubborn. They are typically purposeful, selective, and experienced.	Tend to solve problems with as little wasted effort as possible. They prefer to "stick it out" by choosing a representation and completing the problem.
Persona 2 5 practitioners	*Evaluative:* This practitioner typically uses 2 representations. They tend to be less confident in the representation. Often times they are problem checkers.	Rely on a defensible and trustworthy representation. They are not afraid to move on if they get stuck.
Persona 3 3 practitioners	*Indecisive:* This practitioner has a more difficult time choosing and staying with a representation when solving the problem.	Solve the problem with the least amount of effort. Values mental strain over total time. Will quickly move on if the representation is too difficult to use.

izations based on the problem-solving behavior of engineering practitioners. These personas define boundaries between problem solver approaches and decisions that may be related to problem solvers in similar disciplines. The results of this research do not conclude that one problem solver persona is better than another, rather we look to explain the types of problem solvers and the general characteristics we encountered. The personas are defined and summarized in Table 6.

4.1 Persona 1

The eye tracking data characterizes Persona 1 (P1) as a *committed* problem solver who refers mainly to one representation and spends little time fixating on the other three representations. The eye tracking data characterizes P1 as spending at least 60% of their time on one representation with less than 30% spent referring to their second most used representation, and 10% on their third. On average, P1 spends 75% of their time referring to one representation. Of the remaining 25%, P1 spends on average 17%, 6%, and 2% on their second, third, and fourth most referenced representations, respectively. The significant difference between the first and second two fixation duration percentages, is unique to P1 and this shows how much more committed they are to using one representation. Additionally, their limited reference, 8% on average, of the two least used representations means they spend much less time with these representations compared to their preferred representation.

P1 is described as a *committed* problem solver because they primarily use one representation to solve the problem. P1 may refer to other representations when familiarizing themselves with the problem or during the problem-solving process, but they remain committed to their initial choice in representation. Characteristics that are unique to P1 are confidence in the representations and themselves, a concern for speed when solving the problem, and relative experience that leads to the purposeful selection of a representation.

P1 often displays confidence in the representations when justifying their preference and when using the representations. Two examples of this come when asked why they chose a particular representation, "***that's the way it's done***" and "***it's the approach I always take***". P1 has a representation they prefer based on their confidence in using that representation. There is little wavering from their initial choice in representation based on their experience. Another example of this is, "*And I noticed that the table on the very right, the 8-inch pipe table, had a column for head loss, and **I knew I could figure out the velocity** based on the flow rate and the pipe size, and so I just followed it right across*". Here P1 describes a sense of confidence and trust in their ability to calculate velocity as part of using a particular representation. This sense of confidence is in the representation itself, but also in the problem solver's own ability to complete the task required. When asked why they did not choose other representations, they appear so confident in their initial choice such that the other representations were of no use to them. Two examples of this are, "*Again, the minute I saw the problem, I went straight to Hazen Williams. **I didn't even think that the Darcy Weisbach was necessary***" and "*I just read the problem and went with it, and **I didn't look at any of the graphs***". In both situations P1 is not concerned with the other representations presented. This is characteristic of the eye tracking data that has fixation durations of at least 60% on one representation.

Part of what makes P1 confident is related to sense of comfort and familiarity. Examples of this include, "*Oh, okay. So, just because that's a conversion **I use all the time**. So, **makes me feel good to use it**, I guess*", and "***Maybe just comfort**? I'm not ... I guess the 4 inch, the 6 inch, and the 8 inch, 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***." Here P1 is describing additional justifications for their choice in representation. In each instance a sense of feeling good and comfort can be related to their confidence in the use of a representation. This is also described when justifying why they did not choose another representation as, "***I don't use them a whole lot***." This further describes how familiarity is relevant to their confidence in a representation. Another example of this is described when discussing the deliberation between the two equations.

> "***I personally like*** *the Darcy-Weisbach*. ***I'm very familiar*** *with the Darcy-Weisbach as opposed to Hazen-Williams, and also, like I said, the friction factors in this question, particularly we have Reynolds number, and the friction factor is based on Reynolds number. So that relationship, it could be from Darcy-Weisbach as opposed to Hazen-Williams coefficient. So, the coefficient made the difference, really*."

We relate P1's sense of familiarity and comfort to their confidence in a representation as characteristics of trust. They rely on past experiences and what makes them "*feel good*" when solving the problem. The sense of feeling good and liking a representation makes them more apt to remain committed when solving the problem.

P1's concern for speed when solving the problem is also used as a justification for their selection of a representation. An example of this is when P1 is describing their decision between an equation and a table to solve the problem. When asked why they choose the tables they state, "*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***". The time required to solve the problem had an effect on their selection of a representation. P1 also relies on other problem-solving heuristics that they associate with speed. An example of this is, "*And use the units to get the right answer,* ***so that's a tool that I use****, and so that helped guide me****, especially trying to do something quickly*** *as a first shot at it, just cancel the units and see where that gets you*". Their mention of "***a tool that I use***" describes the heuristic, specifically that of unit cancelation, that helps guide them through the solution process. They rely on this heuristic in response to their choice in a representation that provides a *quicker* means to solve the problem. Another example of P1's concern for speed is revealed when asked why they did not choose another representation. They state, "*Well, they're essentially the same thing but in visual form. I've used the 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***". Speed is related to P1's *committed* problem-solving behavior as they are less likely to abandon their efforts in an attempt to remain efficient with their time.

P1's relative experience also leads to purposeful selection of representations. In the previous quote, when comparing two representations and why they chose one over the other they state, "***They're essentially the same thing but in visual form***". P1 understands the relationship between two representations and how they are attempting to relay the same information. P1 has experience with both representations and have their own understanding of the advantages of using one representation over another. Their internal deliberation between representations suggests some judgement in their decision making that in this instance, is related to their need to solve the problem "*fast*".

Another example of this judgement that is also related to solving the problem quickly is "*Under this context, it would. If* ***it were accuracy or I was programming something for variability****, I would use the equation*". The deliberation between the representations based on the needs of the problem suggests additional purposeful selection of a representation. In this instance, their selection of a representation is related to the context of the problem and the perceived value or use of the solution. Determining a static answer is much different than creating a dynamic solution that can be used as part of a model or for other applications. P1 purposefully selects the representation that produces a static answer in an attempt to solve the problem more quickly.

P1 is also described as *committed* because they will choose an approach and work their way through the problem even if the approach proves to be difficult. When describing their problem-solving process, they stated, "*And then I started remembering how complicated interpolation was and decided it probably was foolish****, but I charted that course and thought I'd see it through***." This shows how even when P1 appears to doubt the representation they initially chose, they remain *committed* and solve the problem. This type of problem solver has made up their mind and at times may appear stubborn with their decision by not abandoning their efforts.

P1's committed problem-solving behavior agrees with their narrative and eye tracking data. P1's confidence in the representations and themselves, concern for speed, and purposeful selection of a representation is characteristic of the eye tracking data that shows limited reference to more than one representation.

4.2 Persona 2

Persona 2's (P2) evaluative behavior is characteristic of the eye tracking data that shows a more distributed pattern of fixation durations on the representations. P2 is characterized as spending 50–60% of their time with one representation, more than 30% with another, and less than 10% with the other two representations. On average, P2 spends 53% of their time with their first choice of representation and 35% of their time with their second. The average use of the second representation is nearly double compared to P1. The near doubling and the decreased difference between the two most used representations means P2 relies more on at least one other representation when compared to P1. Their third and fourth most used representations average 8% and 3%, respectively. The 11% average fixating on the two least used representations is greater than P1 showing that more time is also spent referring to the other representations.

P2's *evaluative* behavior is described by their perusal of the representations and their problem checking behavior. Overall, P2 problem solvers tend to exhibit less committed problem-solving behavior when compared to P1 problem solvers. P2 is described as an evaluative problem solver who spends more time deliberating between the approaches to solve the problem. P2 may spend additional time evaluating approaches before proceeding with the problem or checking their solution. Characteristics that are unique to P2 include a more thorough evaluation of the representations, a lack of confidence in the representation, a concern for simplicity in a representation, and a tendency to want to check their answers.

P2 is considered evaluative due to their more thorough perusal of the representations. For example, when asked how they determined which representation to use they stated, "*Since you have different formulas and things spread out throughout the screen **I just kind of perused**, which ones had to do with what formulas and degree of effort*". Here P2 is describing their evaluation of the representations in order to determine which they prefer to use. In this case their preference is related to the degree of effort associated with the use of the representation. This is characteristic of the eye tracking data which has the fixation duration on one representation between 50 and 60%. This provides up to an additional 10% of their problem-solving time to fixate on additional representations when compared to P1. These additional fixations on representations are related to their time spent evaluating, switching to a different representation, and checking their answers.

P2 is considered less confident in the representations as they are likely to switch to a different representation mid-solution. An example of this is, "*So, I think I first was starting with Darcy and then **I realized that wasn't the best way to do it so I went back and just went and used Hazen** because it was, most the information was there*". Their need to change representations because it is not the "*best*" approach is related to their lack of confidence in the representation. This is explicitly mentioned when asked why the representation was not the *best way* as a, "***Lack of confidence** in my ability to apply the Darcy equation accurately today*". Their lack of confidence makes this problem-solver more likely to abandon an approach mid-solution.

P2 is also concerned with simplicity when justifying their use of a representation. An example of this is included in a previous quote where they state, "*which ones had to do with what formulas and **degree of effort***". Part of P2's evaluation and eventual choice of a representation is dependent on how simple it will be to use the representation. Further examples of this include, "*That flow rate chart, the one in the middle, **is the easiest it seems like**. It just shows the flow rate, five sides. Get the head loss*" and "*What made me choose it? Probably a little bit of familiarity or **what I saw initially as ease***". Their reliance on simplicity is related to their initial choice of a representation but also used as a reason for explaining the benefits of a representation.

> *I do like the tables, like I said they've gone through and **simplified the math it's very easy to punch the wrong number on a calculator**, whether using that on an actual calculator or your phone or Excel or something. It's extremely easy to make a silly typo that throws you off and throws everything out of whack.*

This example shows how P2 is concerned with simplicity as a means to reach a more accurate or trusted solution. There is a level of judgment associated with their deliberation between representations that relies on the simple use of the representation and the benefits of making it simple to use.

Simplicity is also related to the availability of the information in a representation. An example of this is, "*The **accessibility** of the constant C. That was **available and without going through all the charts and stuff***". This describes the simplicity of having information available and not needing to interpret parts of other representations. Simplicity is also described when P2 states, "*I mean I think that's why I went to the tables initially because it seemed **pretty straight forward***". P2 chooses a representation based on it being easy to understand, describing it as "*straight forward*".

The simplicity of the availability of information further describes P2's evaluative problem-solving behavior.

> "*Read the problem. See what was in there. Take a look at **the available information** that's on the screen, what is being presented**, what seems to be most reasonable**. I also **jumped back a couple of times** just to review the information that was in the problem statement. Make sure that what I was looking for and anticipating was there, or if I had to assume something, or derive something. And that helped me, also, to focus more on the Hazen-Williams approach.*"

How P2 judges the available information and what is most reasonable describes their evaluative approach to the problem. P2 is looking at the information in each representation and determining which of them they understand and how they will solve the problem. They describe needing to return to the problem statement frequently as they determine which representation to use. The time and effort P2 expend describes their evaluative behavior.

Part of P2's time spent fixating on other representations is related to their concern with checking their answers. This could be thought of as an additional lack of confidence as well as an underlying problem-solving behavior to check a solution. An example of this is; "*I eventually went into converting the flow to use the eight-inch table along with the [Hazen] and then* ***I wanted to double check myself*** *and just looked at the [Figure] in the middle on the bottom.*" Even though P2 has determined an answer with their initial choice in representation, they describe the need to "*double check*" themselves. Additional examples include, "*although* ***I went back and tried to verify it*** *with kind of two different methods*", and "*But then I was* ***double checking my work****. So, I was using both the tables and the Darcy*". A justification for needing to double check is described as uneasiness with the simplicity of the problem.

> "***It makes me want to double check****, though, sometimes when* ***something seems a little too easy*** *then you want to* ***double check yourself*** *with more formulaic way vs. a table that was developed but the tables are usually developed for a reason.*"

Here P2 initially uses the tables because they are simpler than a formula but does not have enough confidence in the table because it "*seems a little too easy*" and has to "*double check*" their solution.

P2's narrative and eye tracking data describe their evaluative problem-solving behavior. Their lack of confidence in a representation, concern for simplicity, and need to check their solution is unique to P2. This is characteristic of the eye tracking data that shows multiple references to representations with a closer distribution of fixation durations between two or more representations.

4.3 Persona 3

The eye tracking data characterizes Persona 3 (P3) as an *indecisive* problem-solver due to a much more distributed pattern of fixation duration percentages on each of the four representations. The eye tracking data characterizes P3 based on their fixation durations not exceeding 50% for any one representation. Additional characterizations are spending at least 30% and 10% on two other representations. The average time spent fixating on the most used representation is 45% with 33% spent fixating on their second most used representation. The smaller difference between these two fixation percentages, suggests that P3 has a more difficult time determining which representation to use. Fixation durations for the two least used representations are 17% and 5%, respectively. The average of 22% spent on these two least used representations is double that of Personas 2 and 1. This is a considerable increase that highlights P3's more distributed fixation patterns that is described as *indecisive* problem-solving behavior.

P3's *indecisive* behaviors are related to their motivation for simpler methods and a lack of familiarity with information in the representations. Even though these problem solvers self-identified as having experience with headloss problems, we suggest that they may not be as familiar with the concepts as the problem solvers in Personas 1 and 2. P3 has difficulty determining which representation to use and often moves through each trying to determine which they prefer. P3 does not completely evaluate their options or understand all the information presented in each representation. Characteristics that are unique to P3 are a more significant reliance on the simplicity of a representation, limited evaluation of the representations, and a lack of familiarity with the information within the representations.

P3 is more motivated to choose a representation based on how simple it is to use. When asked why they chose a particular representation they stated, "*Experience has taught me that I need to* ***find quicker, easier methods****, and if someone's already calc'ed it out for me, should probably follow that*". Another example of this is, "*I started reading left to right, and the better I understood the problem, and the more I understood what I was looking at on the charts, the more* ***I leaned towards something that made it simpler to solve***". The use of the words "*easier*" and "*simpler*" to describe the representation means that P3 is concerned with the simplicity of the representation and the level of effort they will have to put forth to solve the problem. Choosing a representation based on the level of effort it will require is further described as, "*Well, it looked like the chart was, above that,* ***was pre-calculated for me****, so I could* ***avoid crunching the numbers*** *by looking at the chart.*" P3 is looking for a representation that does not require as much work as another representation. P3 is also less likely to choose a representation that appears incomplete because it will require more effort to solve the problem. An example of this is, "*Well, I looked for* ***which context had the most pieces of information*** *to* ***get to the solution without having to figure out other things****, like an equivalent roughness, or those other things*". P3 prefers a simpler representation and is less likely to put the effort into figuring things out.

P3 also relies on simplicity when describing their interpretation of the needs of the problem. This is shown in a response for the main reason they choose a representation as, "*It* ***seemed simplest I guess****, to see the* ***rough estimate****"*. Here P3 is describing their concern for an answer that provides a rough estimate. Another example of this is, "*I guess I've used Hazen-Williams more often in* ***estimating*** *versus whenever we used Darcy in college, it was an* ***iterative process and therefore avoided***". Their need to estimate the answer is motivated by the lack of simplicity when completing an iterative process. Their choice in representation is further justified as "*Yeah, tried to figure out what,* ***how accurate you wanted the answer*** *because that changes what I would use.*" This is similar to a previous statement in P1 that relates the context of the problem to the choice in representation. Here P3 is motivated by simplicity to find a solution that is context dependent, rather than speed as in P1.

P3 also exhibits a lack of familiarity with the information within the representations that is unique to this persona. This lack of familiarity often causes them to abandon their efforts mid solution. When asked why they moved from one representation to another they stated, "*Well, I tried to use the bottom, middle one. But,* ***I couldn't find the right flow rate*** *to go with the pipe size. And so* ***I went to the table instead***". Each representation provides enough information to solve the problem. If the terms or some of the information is not immediately apparent to P3, they get stuck and move to a different representation. Another example of this is:

> "*All right, well the very last portion said, "Assume a Reynolds number," so immediately I thought, "Well, maybe I should use the Reynolds number chart. After not seeing what I was looking for there, and honestly since I haven't dealt with the Reynolds number in a long time, I was looking for another way around it. So,* ***I looked to see what other information I had available****. The flow rate chart at the bottom looked promising, looked fairly simple, and* ***then I realized it didn't have the information I needed*** *as well. Moved on to the top right, and immediately noticed that I was given the velocity for the eight inch with the relative roughness, and so I used that chart with the velocity and was able to calculate the exact velocity, and the head loss by interpolation.*"

In this example they are trying to choose which representation they prefer to use to solve the problem. Even when the representation seems "*fairly simple*" they are unable to find the information they need to solve the problem. P3 eventually relies on a representation they determine to be more complete.

P3's narrative and eye tracking data identify their indecisive problem-solving behavior. Their reliance on simplicity, lack of familiarity with the information in representations, and limited evaluation of the representations is characteristic of the more distributed fixation durations amongst all four representations.

4.4 Persona exceptions

In addition to the problem solvers described in the three 3 personas, two problem solvers are considered outliers as they did not align with the comparison of eye tracking and retrospective interview results. These two problem solvers were characterized as *committed* with the eye tracking data but *evaluative* with the retrospective interview data. They spent most of their time viewing one representation but their narrative characterized them as more of an evaluative problem solver. In both instances these problem solvers used more than one approach to solve the problem. One of the problem solvers was just over the threshold for the eye tracking characterization which would suggest the interpretation of their narrative to be different. The other problem solver primarily used two approaches with negligent reference to the other two approaches. This would allow for a majority of their time to be spent on one approach while also being able to use another approach in the problem-solving process. We suggest that these problem solvers exhibit characteristics of both Personas 1 and 2 and represent a grey area between problem solver personas that could be analyzed in future research.

5. Discussion

The discussion of our analysis will focus on the problem solver personas and their implications. Additional discussion is provided on representation use and the synergistic interaction of the methods and data sets.

5.1 Personas

Each of these personas describe a type of problem solver; however, a person may not be restricted to one problem-solving persona. These personas may be associated with the context in which the problem is situated. This would suggest that problem solvers may move from one type of persona to another based on the features or needs of the problem and the environment in which it is presented. Practitioners discuss how they may use a different representation based on their perceived needs of the problem, such as accuracy and time. Some practitioners would make decisions based on what they perceived to be our expected level of accuracy. This suggests that in a real-world problem, a practitioner may solve a problem differently based on the needs of the client. This could cause the practitioner to exhibit different behaviors or characteristics that could change the persona in which they are portraying.

The implications of these problem-solver personas suggest that engineering practitioners are not rigid, programmed calculators set out into the world to solve problems. Practitioners are required to negotiate a myriad of constraints and contexts associated with the problems they solve that determines which problem-solving persona they embrace. If the context of the problem dictates the problem solver persona, much is left to understand about the varying contexts of engineering practitioners and how that compares to the academic context that students participate in.

What we see in our classrooms does not necessarily change once students become engineering practitioners. We suggest that their behaviors as problem solvers has an impact on how they solve problems in the engineering workplace. If an engineering student portrays the same *committed, evaluative*, and *indecisive* personas described in this study, it may be important that educators facilitate environments where all of these types of problem solvers can succeed. Engineering students will become a contributory member of their discipline in their own regard. This study presents a better understanding of engineering practitioner problem solving that could assist in the preparation of students for the classroom to workplace transition.

5.2 Representation use

Based on the eye tracking data, the engineering practitioners spend varying amounts of time fixating between representations. Each engineering practitioner has a unique way of solving the problem and even though there are patterns of behavior, no two engineering practitioners behave in the exact same way. We found no meaningful relationship between a practitioner's representation use, total time, and problem correctness. This suggests that there is no one representation that is better at solving this problem.

Previous research in metarepresentational competence has focused on the affordances of representations. These affordances describe how representations offer certain information and to what extent is that information efficiently comprehended [7, 60, 61]. Considering the nature of this research study, representational affordances could be additional underlying factors for an engineering practitioner's decision to solve the problem with a particular representation. However, these affordances are related more to the physical and conceptual information of the representation than they are to the justifications of a problem solver. Future research could focus on the relationship between a problem solver's justification and the affordance of a representation in an attempt to understand more about representational use and the characteristics of problem solvers.

5.3 Methods

The combination of the eye tracking techniques and retrospective interviews proved to be valuable in our analysis of problem-solver personas. Both data sets provided a unique perspective of the problem-solving process. However, these data sets would not have provided the same analysis on their own. Multiple instances occurred in the analysis where the interviews or the eye tracking data did not entirely agree on which representation was used to solve the problem. The synergistic interaction between the methods allowed us to provide more narrative to the eye tracking data while the eye tracking data assisted in gathering a more robust narrative. This synergy was foundational to our findings and could be valuable in similar studies moving forward.

5.4 Limitations

Some limitations of this study include the context of the problem-solving interview, depth of the problem, and the limited representations provided to solve the problem. Practitioners are asked to solve problems that may not be similar to the way they solve problems in a workplace context. A workplace is driven by client needs, is typically collaborative, and the resources may be different. The context of our problem-solving interview may have an influence on representation use which could have an effect on the designation of the problem-solving persona of the engineering practitioners. Future research could focus on the differences between these contexts and how that affects problem solving decisions. Additionally, the problem presented to participants is not a complex open-ended design problem that engineer practitioners would typically solve in the workplace. This problem has one unique answer that can be determined with a limited number of resources. This problem was intentionally chosen with a limited number of representations to help understand *why* specific decisions are made. Future research could also include more authentic open-ended design problems with additional resources.

5.5 Implications

Results from this study and similar studies on student problem solving personas can help improve our understanding of the gap between engineering experts and novices. A considerable amount of engineering education research is focused on understanding and bridging the gap between engineering practitioners (experts) and engineering students (novices) [1, 3, 27, 55]. We are not suggesting that educators find ways to mimic these personas in the classroom. We do suggest however, that understanding more about these personas could lead to a better understanding of problem-solving behavior in varying contexts including the engineering workplace and the classroom.

This research shows how engineering practitioners express different reasons for choosing representations. We suggest that students may benefit from learning the pros and cons of these reasons when solving problems. If underlying reasons guide expert problem solvers through the problem-solving process, it may be important that educators understand *how* and *why*. Continued research in problem-solving personas could lead to additional predictions or assumptions about problem solvers that could assist in the development of better teaching practices.

6. Conclusion

The purpose of this research was to determine how the behaviors of engineering practitioners describe specific types of problem solvers. This research addresses the gap in previous literature surrounding the understanding of engineering practitioner problem solving behavior. This gap was addressed through the emergence of three problem-solver personas that describe how engineering practitioners interact with representations and what reasons they give for their interactions. The results demonstrate three personas that describe a *committed*, *evaluative*, or *indecisive* problem solver. These results suggest that individual practitioners have unique ways of behaving during problem solving that is associated with their experience and the context of the problem. The personas in this study relied on the combination of the eye tracking and retrospective interview data sets to characterize distinct problem solvers. The justifications discovered in this study are underexplored in engineering education research and provided a more holistic understanding of the problem-solving characteristics of engineering practitioners that led to those characterizations.

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