

Board 68: Problem-Solving Rationales of Practicing Transportation and Hydraulic Engineers When Provided Multiple Contextual Representations

Dr. Masoud Ghodrat Abadi, California State University, Sacramento

Masoud Ghodrat Abadi is an assistant professor in Civil Engineering at California State University, Sacramento. He received his PhD in 2018 from Oregon State University. He is a member of standing committee on Education and Training in Transportation Research Board (TRB).

Mr. Sean Lyle Gestson, Oregon State University

Sean Gestson is a recent graduate from the University of Portland where he studied Civil Engineering with a focus in Water Resources and Environmental Engineering. He is currently conducting Engineering Education research while pursuing a doctoral degree in Civil Engineering at Oregon State University. His research interests include problem solving, decision making, and engineering curriculum development.

Dr. Shane A. Brown P.E., Oregon State University

Shane Brown is an associate professor and Associate School Head in the School of Civil and Environmental Engineering at Oregon State University. His research interests include conceptual change and situated cognition. He received the NSF CAREER award in 2010 and is working on a study to characterize practicing engineers' understandings of core engineering concepts. He is a Senior Associate Editor for the Journal of Engineering Education.

Dr. David S Hurwitz, Oregon State University

Dr. David Hurwitz is an Associate Professor of Transportation Engineering in the School of Civil and Construction Engineering at Oregon State University and is the Director of the OSU Driving and Bicycling Simulator Laboratory. Dr. Hurwitz conducts research in transportation engineering, in the areas of traffic operations and safety, and in engineering education, in the areas of conceptual assessment and curriculum adoption.

Problem-Solving Rationales of Practicing Transportation and Hydraulic Engineers When Provided Multiple Contextual Representations

Abstract

This research documented the glance patterns and conceptual understanding of practicing engineers attempting to solve conceptual exercises with different contexts. Two mechanisms for data collection -- eye-tracking and reflective clinical interviews -- were employed to more holistically understand practicing engineers' interaction and reasoning while solving transportation and hydraulic design problems. Data collection involved the use of three carefully developed questions in both transportation (with 3 contextual representations) and hydraulic design (with 4 contextual representations). The process required each participant to sit in front of a computer monitor that displays the problem statement and each of the contexts on a single slide. The participant was required to wear the eye tracking equipment while they solved the problems and their eye movements and focus patterns were collected. During the experiment, the participants completely solve each of the presented problems. If necessary, the participants were allowed to ask clarifying questions. Once the participants completed all three problems, the eye tracking equipment was removed and the post retrospective interview was conducted and audio recorded. Each of the participants was asked the same series of questions that focus on the problem-solving process. In total 25 engineering students (17 hydraulics engineering students and 14 transportation engineering students) and 52 practicing engineers (28 hydraulics engineering students and 24 transportation engineering students) participated as subjects in the data collection efforts. Based on our current literature review, this is the largest eye-tracking / reflective interview study of problem solving that has been conducted to date. The interview and visual attention data was used to document seven (comprehensive, experimental effect, familiarity, judgement, simplicity, speed, and stepwise) problem solving rationales in response to the transportation engineering questions and five (speed, familiarity, accuracy, confidence and simplicity) problem solving rationales in response to the hydraulics engineering questions.

Project Goals

There are four main goals associated with this project. They are as follows:

I. Collaboratively identify relevant concepts and contexts with students, faculty and practicing engineers. Here we define practicing engineers as having 1) the expertise of the responding transportation professionals emphasized combinations of signal timing, urban planning, and transportation design or expertise on pressurized pipe flow 2.) participants had a range of experience from 2 to 17 years, and the sample was approximately 40 percent women. This project is focused on two specific areas of engineering (traffic signal timing and pressurized pipe flow). Specifically, we will use 6 semi-structured interviews with transportation engineers and 6 semi-structured interviews with hydraulics engineers to help develop authentically situated engineering design problems and contexts.

II. Document glance patterns and conceptual understanding of engineering students and practicing engineers attempting to solve conceptual exercises with different contexts. Two mechanisms for data collection -- eye-tracking and reflective clinical interviews -- will be employed to more holistically understand engineering students' and practicing engineers' interaction and reasoning during conceptual exercises. Participants will attempt to solve

conceptual exercises presented with three to five contexts, each in the content areas of traffic signal timing and pressurized pipe flow. Each context will provide information that facilitates the participant in solving the exercise. A robust Beta test of all experimental procedures will be conducted to ensure that each context presented is useful for solving the particular exercise, to make sure the conceptual questions elicit insightful responses, and to refine the details of the data collection.

III. Synthesize quantitative data on glance patterns in conjunction with the qualitative data on engineering student and practicing engineer ways of thinking. The glance patterns and interview data will be considered at three levels: for individual participants, for individual content areas, and for all participants.

IV. A workshop will be planned and attended by students, faculty, and practicing engineers. Participants will receive an orientation to conceptual knowledge and contextual representations and will work in facilitated groups. Pilot curricula and guidelines for curricular development will be developed that more accurately account for the influence of factors such as context. The synthesis of glance patterns and reflective clinical interviews will contribute to uncovering the influence of context in conceptual understanding of both experts and novices. This new knowledge will be applied to pilot curricula for the topics of traffic signal timing and pressurized pipe flow engineering and will be refined into a best practice guideline for the development of curricula across engineering disciplines.

Background on Eye-Tracking during Problem Solving

Researchers have proposed that eye-tracking could distinctly describe problem-solving practices (Bazar, 2007) and cognition (Pellgrino et al., 2001). Eye-tracking refers to the application of technology to measure the activity of the human eye and is based on the “eye-mind” assumption (Just, 1980) which suggests that eye movements correlate with attentional focus and cognitive processing (Lia et al., 2013). Eye-tracking measures where, when, and for how long individuals look at different features in their field of view. Common eye-tracking measures include data in the form of eye fixation locations, fixation durations, saccades (eye movements between fixation locations), and saccadic durations (Tai et al., 2006). Mayer (2010) has suggested that, “eye-tracking measures, such as total fixation time on relevant areas of an instructional graphic, can be successfully added to a researcher’s toolbox as a way of testing hypotheses about perceptual processing during learning under different instructional methods” (Mayer, 2010). Therefore, in response to the lack of knowledge regarding the influence of CRs on the problem-solving approaches of transportation engineering practitioners, this study employed an eye-tracking technique.

Project Activities

The workshop activities were designed to effectively achieve the workshop goal stated in the previous section. The following key points summarize the overall workshop activity.

Data Collection

Data collection requires a participant to sit in front of a computer monitor that displays the problem statement and each of the contexts on a single slide. The participant is required to wear the eye tracking equipment while they solve the problems and their eye movements and focus

patterns are collected. During the experiment, the participants completely solve each of the presented problems. If necessary, the participants may ask clarifying questions. Once the participants have completed all three problems, the eye tracking equipment is removed and the post retrospective interview is conducted and audio recorded. Each of the participants is asked the same series of questions that focus on the problem-solving process for each problem and the relevance of the contexts and problems. The data collection process started after official approval from the Institutional Review Board (IRB) at Oregon State University (study number 6959). The following questions are asked in each of the post retrospective interviews:

- When looking back at your solution to problem #, what made you choose the method you did?
 - Are you familiar with the contexts provided with problem #?
 - Is simplicity a concern 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/signal phasing important to work you do?

Figure 1 presents an example of the eye-tracking and clinical interviews that were implemented in this experiment.

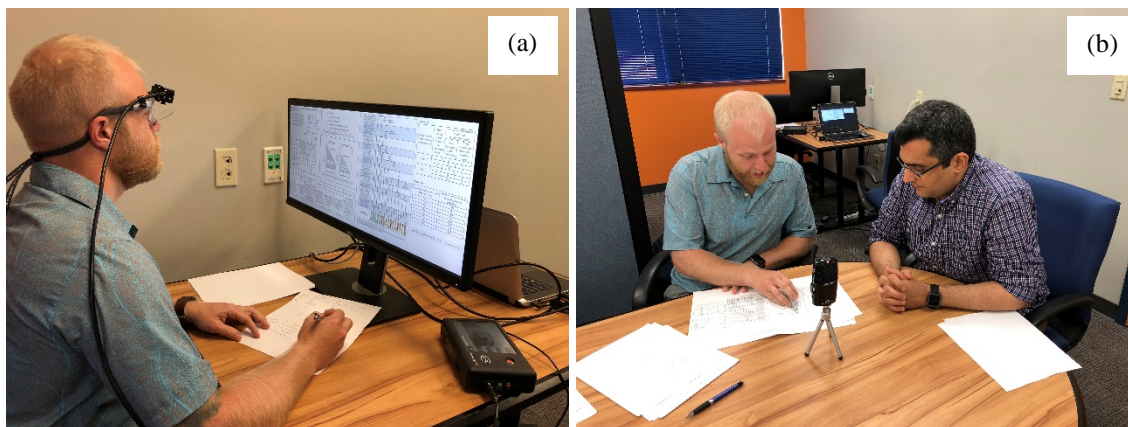


FIGURE 1 Data collection process: (a) eye-tracking, and (b) reflective clinical interview

In total 25 engineering students (17 hydraulics engineering students and 14 transportation engineering students) and 52 practicing engineers (28 hydraulics engineering students and 24 transportation engineering students) participated as subjects in the data collection efforts. Based on our current literature review, this is the largest eye-tracking / reflective interview study of problem solving that has been conducted to date.

Data Reduction

All interview data for the practicing engineers and the engineering students has been transcribed and all of the interview data from the practicing engineers has been fully coded and analyzed using qualitative data analysis software (Dedoose). The coding process was completed through in-vivo techniques where each code was based on the words of the participants (1).

All of the visual attention data from the engineering students has been segmented, the Areas of Interest (AOIs) have been Coded into the video files, and comma separated variable files have been extracted from the analysis software (ET Analysis).

Interview Data Analysis

The interview data was used to document problem solving rationales. Nine rationales were identified in the professional engineers based on their interview data.

Visual Attention Data Analysis

The visual attention data was visualized, descriptive statistics were calculated, and statistical tests were performed on the measures of total and average fixation duration.

Dissemination of Workshop was organized and executed

On May 22nd and 23rd, the Transportation Engineering Education Workshop (TEEW) was held in Auburn University Hotel and Dixon Conference Center, Auburn, AL. Forty-five academic experts, with diverse set of expertise, gathered together to discuss the most important issues of current efforts in transportation engineering education. As part of this 2-day workshop, researchers of the current study presented their work through two 1-hour sessions.

During the first half of the presentation, TEEW participants received an orientation to conceptual knowledge, the theory of situated cognition, and the impact of contextual representation on the problem-solving capabilities of practicing engineers and engineering students. They were then provided with an introduction to our study and its methodology, and were presented the process undertaken to identify prominent concepts and contexts for the transportation engineering design problems. The developed problem alongside the three associated contextual representations were included in a hand-out that was distributed among the TEEW participants.

After this 15-minute orientation, TEEW participants were divided into 7 groups and were asked to provide feedback on the developed problem and associated contextual representations. Group discussions were moderated by the researcher team and revolved around 5 main questions:

1. Are the contextual representations authentic?
2. Is the problem authentic?
3. How could we improve this problem or the associated contextual representations?
4. Would you use this problem in a class that you teach?
5. Would you use this approach to design a question for your class?

Results and Summary

Interview Data Analysis & Results

The interview data was used to document problem solving rationales. Here we define problem solving rationales as the way in which the respondent attempted to solve the problem using or

not using the contextual representations provided. The following nine rationales were identified in the professional transportation engineers based on their interview data:

Comprehensive/Detailed

This code refers to a rationale in which a Contextual Representation (CR) is selected because it provides a comprehensive/detailed approach to solve the problem. The comprehensive and detailed nature of the Flowchart caused 4 participants to solely rely upon this CR to solve the problem. The rationales among these participants were very similar and usually included statements such as: *“I relied more heavily upon this flowchart here because it seemed to be just a little bit more detailed than was this [Graph]”*.

Experimental Effect

This code refers to a rationale in which a CR is selected due to its placement on the screen or by overlooking problem description or other CRs. One of the limitations of the present study is the role of experimental effect on CR choice. In fact, the problem-solving approach for 3 participants were affected by the positioning of CRs on the screen. For example, in response to the question, *“Why did you spend quite a long time evaluating each individual CR and then moving from one to another?”*, one engineering practitioner indicated that: *“I didn't, at first, look to see what everything was. I kind of took it piece by piece and looked at each one in turn. Had I looked at everything beforehand, I might have gone straight to the flowchart. But ... I just looked at the problem then kind of went through each of the pieces from left to right”*.

Familiarity/Comfortable

This code refers to a rationale in which CR is selected because it is more familiar to use and is often described as a comfortable choice. Similar to previous research, this study showed that familiarity, and the comfort that arises from it, are determinants in solving problems. Familiarity and subsequent comfort are used by 4 of the engineering practitioners as a description for their engagement with Flowchart as their final choice of CR. For example, when asked about their reason for choosing Flowchart, one of the participants said: *“I did look at all three of these [CRs], and I did end up using the flowchart. I think at the beginning, I spent a little bit of time looking at this method [Graph] from the Traffic Engineering Handbook ... Well, it's not something I use as much so as ... Trying to think if I liked that method or not ... So, I settled on the flowchart method, I felt more comfort using the flowchart because it is typically what I use if I am just going out and building a new intersection”*.

Judgement

This code refers to a rationale in which a CR is selected based on the participant's engineering judgment of the level of accuracy that it provides. Engineering judgement was found to be the major reason behind the choice of a CR to design a left-turn treatment at a signalized intersection. Six participants relied upon their judgement to choose a CR. In fact, the level of accuracy that was perceived by each participant from each of the CRs played a pivotal role in the engineering judgement. For example, when asked about the reason for using both the Graph and Flowchart, one participant mentioned that: *“I assumed they both were valid and accurate contexts to use and so I decided both of them ... Depending on the answer they gave, both of them could work”*.

Simplicity

This code refers to a rationale in which a CR is selected because it requires less work and effort to solve the problem. From the 24 participants, 4 only selected the Graph due to the perception of reduced complexity. This was especially important for those participants who were not familiar with the provided CRs: *“I don't think I've seen the ITE [Graph] or the traffic engineering formulas [Equation] before ... I started with the ITE charts [Graphs] because they're super simple”*.

Confidence

This code refers to the rationale for *confidence* which is related to an engineering practitioner's confidence in a CR or their ability to use that CR. This rationale can also be thought of as trust that a CR will provide the right answer. A common example of this is, *“I could use Darcy-Weisbach because I know I could solve for the friction factor because I had Reynolds and I had the roughness so I used moody chart to get F”*.

Speed

This code refers to a rationale in which a CR is selected because it provides the quickest means to solve the problem. Speed was considered a key CR preference for 3 participants. Here, the Graph was more frequently referred to as a quick approach: *“The graph is a quick ... for me it was used as a quick guide to determine, should I even evaluate any further, based on just two factors. Just, what's my volume? What's my speed?”*

Stepwise

This code refers to a rationale in which a CR is selected because it provides a step by step approach to solve the problem. For 3 of the participants, the Flowchart was selected as the CR due to its stepwise procedure: *“There was more decision points here and I could see If I had a different variable, how would that reset?... I wasn't really sure how to use this exactly. It's pretty straightforward, but at the same time, It's something more ...”*.

Selection Rationales vs. CRs

Table 1 presents the co-occurrence of selection rationales and CRs. As shown in this table, participants most frequently selected the Flowchart due to the level of comprehensiveness that it provides (4/24 participants) and familiarity with this CR (4 participants). The Graph was also chosen due to engineering judgement (4 participants) and the simplicity of using this CR (4 participants). The Equation was only referred to in 2 cases due to its simplicity and engineering judgement.

Visual Attention Data Analysis & Results

According to the literature, eye-tracking can be used to describe problem-solving practices. Data from eye-tracking encompasses several different variables. Some of these variables refer to standardized values (effects neutralized over the entire sample) while others refer to the direct observed values (distinct individual variations). Since the present study attempted to capture distinct trends in the problem-solving practices of individual transportation engineering practitioners, non-standardized variables are adopted. As such, two eye-tracking performance measures were considered: 1) Total Fixation Duration (TFD) in seconds, and 2) Average Fixation Duration (AFD) in seconds. TFD refers to the total length of time for all fixations on a

specific AOI and AFD refers to the mean length of time for all fixations on a specific AOI. Table 1 shows mean and standard deviation values for TFD and AFD across all AOIs for the transportation engineers. In addition to CRs, participants' fixation on the problem statement (problem) and solution (outside) are included.

TABLE 1 Mean and standard deviation of dependent variables against each AOI

Dependent Variable	Descriptive Statistics	Problem	Equation	Graph	Flowchart	Outside
TFD	M (SD)	104.86 (59.52)	23.93 (19.25)	38.25 (23.11)	135.16 (95.74)	167.89 (211.08)
AFD	M (SD)	0.28 (0.05)	0.27 (0.08)	0.25 (0.05)	0.28 (0.05)	0.35 (0.12)

The data in this study was obtained through a multivariate experimental design, as two dependent variables, TFD and AFD were recorded for each individual participant. To analyze the influence of CRs on either of the visual attention measurements, Multivariate Analysis of Variance (MANOVA) was performed to test whether or not the CRs affect TFD and AFD. Additionally, to investigate the interaction of visual attention measurements, data was visualized against each of the CRs. MANOVA results showed that there was a statistically significant difference in visual attention based on CR ($F(10, 274)=6.065$, $p<0.001$, Wilk's $\Lambda=0.670$, partial $\eta^2=0.181$). It was found that CR has a statistically significant effect on both TFD ($F(5, 138)=9.998$, $p<0.001$, partial $\eta^2=0.266$) and AFD ($F(5, 138)=4.847$, $p<0.001$, partial $\eta^2=0.149$).

Project products

Meaningful impacts from our projects include:

- Development of the largest database (83 participants) of eye-tracking & interview design problem data collected and analyzed to date.
- The development of a robust methodology for studying engineering problem solving and contextual representations with eye tracking and reflective interviews.
- The identification and documentation of nine problem solving rationales supported with both visual attention data and qualitative data.
- Training of 45 professors, post-docs, and PhD students in the topics of conceptual knowledge, situated cognition, and contextual representation, and the dissemination of robust authentically situated engineering design problems to those same participants.

Finally, the following peer-reviewed papers have also been accepted for publication as outcomes of the project:

1. Gestson, S.L., Barner, M.S., Abadi, M.G., Hurwitz D., & Brown, S. (In Press) "Problem Solving Personas of Civil Engineering Practitioners using Eye Tracking Techniques," *International Journal of Engineering Education*, Volume TBD, Number TBD, Pages TBD.
2. Abadi, M.G., Gestson, S., Brown, S., & Hurwitz, D. (In Press) "Traffic Signal Phasing Problem-Solving Rationales of Professional Engineers Developed from Eye-Tracking and Clinical Interviews," *Transportation Research Record: Journal of the Transportation Research Board*, Volume TBD, Number TBD, Pages TBD.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 1463769.

References

1. Bazar, N.S. & Brigham, F.J. Eye tracking technology: An introduction. *The Telecommunications Review*, 18. 2007. pp. 46-48.
2. Just, M.A., & Carpenter, P.A. A theory of reading: From eye fixations to comprehension. *Psychological Review*, 87. 1980. pp. 329-355.
3. Lai, M-L., Tsai, M-J., Yang, F-Y., Hsu, C-Y, Liu, T-C., Lee, S., Lee, M-H., Chiou, G-L., Liang, J-C., & Tsai, C-C. A review of using eye-tracking technology in exploring learning from 2000-2012. *Educational Research Review*, 10. 2013. pp. 90-115.
4. Mayer, R. E. Unique contributions of eye-tracking research to the study of learning with Graphics. *Learning and Instruction*, 20. 2010. pp. 167-171.
5. Pellgrino, J., Chudowsky, N. & Glaser, R. (Eds). *Knowing what students know: the science and design of educational assessment*. Washington, DC: National Academy Press. 2001.
6. Saldana, J. *The coding manual for qualitative researchers*. Sage. 2015.
7. Tai, R.H., Loehr, J.F., & Brigham, F.J. An exploration of the use of eye-gaze tracking to study problem solving on standardized science assessments. *International Journal of Research and Method in Education*, 29. 2006.