SIGNALIZED INTERSECTION OPERATIONS - CASE STUDIES OF HOW UNDERGRADUATE CIVIL ENGINEERING STUDENTS ACHIEVE CONCEPTUAL CHANGE AND CATEGORIZE KNOWLEDGE

A Dissertation

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AUTHORIZATION TO SUBMIT DISSERTATION

This dissertation of Howard J. Cooley III, submitted for the degree of Doctorate of Philosophy with a Major in Civil Engineering and titled "Signalized Intersection Operations – Case Studies of How Undergraduate Civil Engineering Students Achieve Conceptual Change and Categorize Knowledge," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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ABSTRACT

The research presented in this dissertation shows the results of two case studies that analyze and explore the conceptual changes related to signalized intersection concepts of undergraduate civil engineering students. Consensus of the literature reviewed for the case studies suggest that failure to experience conceptual change is a major reason why students fail to understand concepts in science, mathematics, and engineering. Although students are successfully passing courses, the literature also concludes that students tend to rely on theoretical equations and have a high regard for their personal experiences and intuition. These deficiencies can be attributed to the situation and environment in which learning occurred.

The case studies presented here work from the constructivist learning theory where situation and learning environment are valued and learning is said to be an active process that integrates previous knowledge and life experiences. Using the constructivist frameworks of conceptual understanding, situated cognition, and conceptual change each case study used a qualitative approach to study conceptual changes from two different learning environments. The first case study analyzed students in an activity and observation based signal timing curriculum and used changes in affordances over a semester as a measure of conceptual change. The second case study analyzed students from a more traditional passive lecture format of an introductory transportation engineering course. Ontological classification and knowledge profiles were used as measures to assess conceptual change.

The results from the case studies suggest that personal driving and experiences have influenced the ways in which students categorize their knowledge. The evidence of personal driving experience found in student responses suggest that students were using a personal driver-like categorization that seemed to exist at a higher priority than transportation engineering-like categorization. These results are relatively new to transportation engineering education and there is no datum for comparison. Therefore it is recommended that the methods presented here be revised and repeated as a measure of validity. Then focus should be placed on adjusting curricula for better learning.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my wife and kids for putting up with way too much at times. Thanks to Dr. Ahmed Abdel-Rahim, Dr. Shane Brown, Dr. Mike Kyte and Dr. Steve Beyerlein for facilitating way too much at times. Thanks to dad and sis. Thanks to Karen for editing and the helpful comments. Thanks to Troy Weiser for keeping contact with old friends. Thanks to the participants of the case studies; I hope you enjoyed your $15. Thanks to all my students for showing me your' learning processes and giving me ideas and thoughts for research. Thanks to Sean, Chad, Robert, Kyle, Justin, Bryan, Scott, and many others who stopped by just to shoot the breeze. Thanks to Teresa, Selena, Bobbie, Colleen, and Brittney for watching the kids. Thanks to the Ruggers for having a beer or two. Thanks to Chuck Brandt for encouraging me to start this venture.

DEDICATION

This dissertation is lovingly dedicated to those who did not see me finish.

Mom, Dawn, Mike, Travis, and Thomas

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CHAPTER 1: INTRODUCTION

Background

Studies in civil engineering education have shown that most students lack an understanding of fundamental engineering concepts even when successfully passing courses. They tend to rely on theoretical equations with limited conceptual backing. While students seem to have a high regard for their personal experiences and intuition, they often cannot make clear connections between concepts and their applications (1) (2). Unfortunately, these trends continue after graduation, as similar deficiencies have been found in practicing transportation engineers (3). These deficiencies are most likely related to the situation and environment in which learning occurred.

Over the past century, engineering curriculum has changed from being highly practical to highly theoretical (4). Current engineering education practices are largely characterized as passive learning environments primarily based on theoretical content with minimal practical field and/or laboratory experience. Students rarely change their pre-conceptions about a certain subject due to passive lectures, because this type of instruction and assessment offers little opportunity for them to resolve misconceptions (1). This method of teaching assumes a "separation between knowing and doing, treating knowledge as an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used" (5). It presupposes that students will be able to apply material learned in lecture correctly in practice. When graduates actually attempt to use learned engineering knowledge in practice, they are often stymied by complex problems and tasks, which require tacit knowledge from the field and is quite different than those found in the classroom.

Constructivist Learning Theory

In contrast to this highly theoretical and passive approach to teaching engineering, Constructivist learning theory posits that knowledge is built not by the is passive absorption of information, but must be actively built by the learner and integrated into previous knowledge and life experiences. Constructivist teaching methodologies are based on the following theoretical approaches to learning: conceptual understanding, situated cognition, and conceptual change.

1. **Conceptual understanding.** Although there is no universal definition of conceptual understanding, it is commonly defined as the understanding of the phenomena underlying a calculation or process including the context, purpose, necessary assumptions, and range of reasonable values expected. Conceptual understanding can be thought of as useful knowledge resulting in an individual being able to apply knowledge outside the context in which it was learned (1). Pre-conceptions and misconceptions play a role in a person's conceptual understanding. A pre-conception is the knowledge about a particular subject that an individual has actively built throughout their life experiences, whereas a misconception is the incorrect or conflicting understanding.

2. **Situated Cognition.** This aspect of constructivist theory views knowing as inseparable from doing and suggests that the situations in which learning occurs affect the way an individual learns a subject (5). Therefore, situated cognition focuses on the "constructive processes of interaction between cognitive agents (students) and the situations they are acting in, rather than manipulation of symbols and equations" (6) (pg.136).

3. **Conceptual Change.** As with conceptual understanding, conceptual change has no universal definition. It can be broadly defined as any type of change that alters how students understand concepts during the learning process, the differences or changes over time with student pre-conceptions or misconceptions, or to more radical changes in existing theoretical frameworks (7).

The inability to experience conceptual change is believed to be "one of the major reasons behind students' widespread failure to understand concepts in science and mathematics" (7).

Objectives

The objective of this research was to use a qualitative approach to study how undergraduate students respond to concepts pertaining to intersection traffic operations to analyze how they experienced conceptual change. The rest of this chapter summarizes the work done for each case study.

The first case study, presented in Chapter 2, is from a research paper presented at the 91st annual Transportation Research Board meeting in Washington D.C. (8). The case study investigated the potential effect of incorporating traffic observation into transportation engineering education on the students' conceptual change. An advanced signal timing class (9), where observation-based activities were the main teaching tool, was used as a case study in this research. A unique aspect of the course was the emphasis of traffic observation through the use of, side-by-side comparison of timing plan changes, training materials from the Mobile Hands-On Traffic Signal Timing Project (MOST) (10), and VISSIM micro-simulation. The unique ways in which the advanced signal timing course was presented and delivered provided an opportunity to observe changes to the pre-knowledge set that students brought to the course.

Using a longitudinal case study approach, measures were taken from student responses from a knowledge survey administered at the beginning and at the end of the semester. The objective of the beginning-of-semester-survey (BOSS) was to capture and document initial affordances. Affordances can be thought of as means of support or the type of support that afforded their ability to respond. The BOSS also determined the kinds of pre-conceived conceptual transportation knowledge that students brought to the course from their introductory transportation engineering course and from their driving or riding experience. The objective for the end-of-semester-survey (EOSS) was to assess conceptual knowledge and affordances after the completion of the course, allowing for an assessment of conceptual change and changing use of affordances from beginning to the end of the course.

Findings from the first case study showed that students increased their use of traffic observation as an affordance condition as a result of the learning environment presented to them in the signal timing course. The increased use of traffic observations in the course was accompanied by an increase in changed responses which implies that traffic observation embedded in the delivery of course content has influenced conceptual change.

Findings also showed that students extensively used pre-conceptions that were personal in nature as affordances to answer in the BOSS. Such personal pre-conceptions are almost non-existent in the EOSS. This, again, showed a major conceptual change where personal insights and perspectives became a less dominating portion of their understanding of the traffic phenomena. Students also showed more improved vocabulary in their EOSS responses. The trends in increased vocabulary were the result of students being involved in group observation activity throughout the class where they had the opportunity to use and present the vocabulary.

Chapter 3 presents the experiment and data collection process for the second case study. The second case study is separated by two different types of analysis that are presented in Chapters 4 and Chapter 5 respectively. The experiment was to conduct one-on-one interviews with 27 undergraduate students who recently completed their introductory transportation engineering course. During the interview, students were asked questions related to actuated traffic signal operations while watching a video of an actuated intersection.

The 3.5 minute video recording of an actuated signalized intersection in Lewiston, Idaho during an off peak period was used to facilitate questioning. The video shows actual traffic processes taking place in real-time and field conditions, and includes multiple traffic behaviors and traffic signal operations common at signalized intersections. The video is completely independent of calculations and isolates the conceptual categorization of the processes the students were questioned about. The interview questions were developed from the observable content of the video. The questions were open-ended without a discrete answer and were intended as a starting point to further provoke conceptual content from the student.

The purpose of the second case study presented in Chapter 4 was aimed at generating hypotheses, theoretical propositions, relevant questions, and research directions for conclusions that would improve curricula for signal timing engineers. The students' interview responses were analyzed within the framework of ontological categorization of knowledge which involves looking into the hierarchical structure of knowledge and the implications it has on conceptual change. A concept is a piece or subset (schema) of this hierarchical knowledge structure. In studying student responses, the researchers looked for how students structured and restructured hierarchical categories of knowledge to determine if conceptual change occurred.

The data were coded by following an approach outlined by Trochim (11), and used by Cooley (8), where the data were read through while listening to the audio in several iterations inductively identifying portions of the student responses that could be considered a category in a process schema. The codes were tallied and assembled into small schemas based on the percentage of the sample that showed a particular code to reveal the collective structure for the entire student sample. An example of one of these schemas is presented in Figure 1.1.

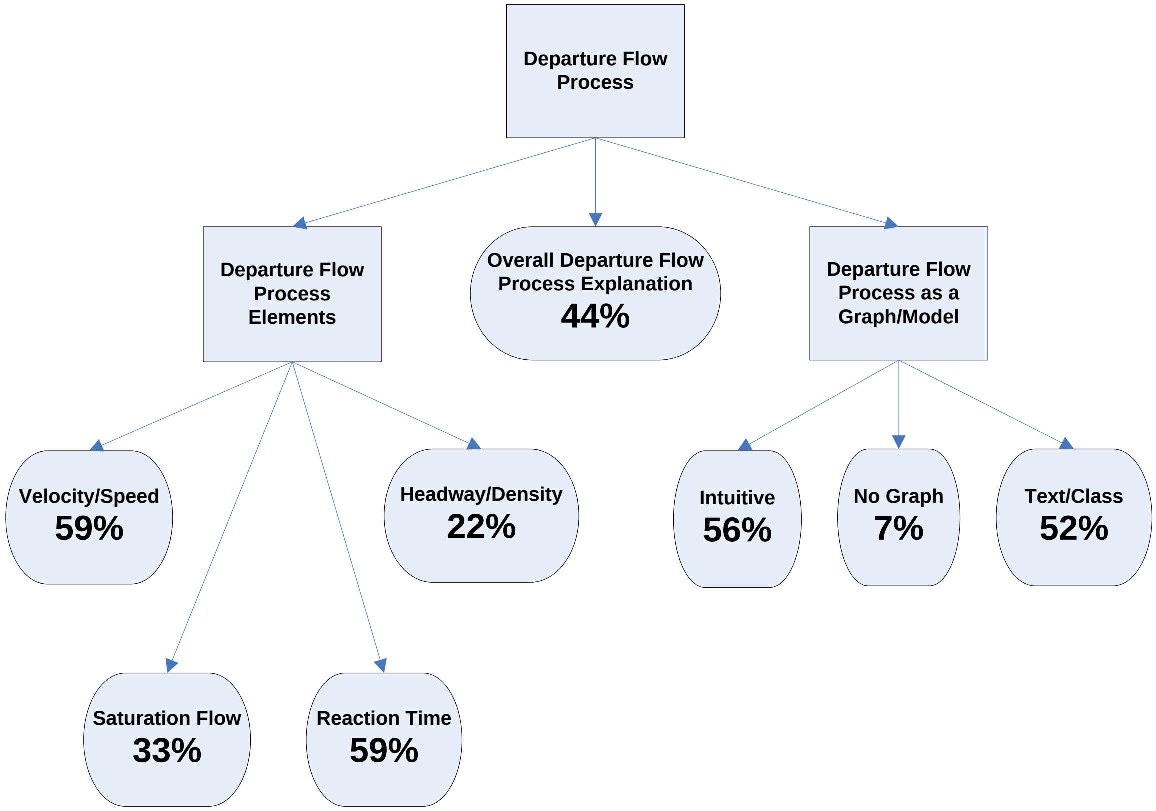


Figure 1.1: Sample schema of departure flow processes developed and presented in Chapter 4. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Among the results of the analysis, six collective schemas were developed. The conclusions derived from this data and the implications for future research directions are discussed next.

Conclusion 1

Student ontological categorization of signalized intersection concepts is limited in depth and provides limited amount of details. The categorization is also disorganized with evidence of misconceptions and disconnected between traffic theory and the application of that theory to actual traffic processes.

Supporting data

- Most of the percentages displayed in the schemas seem low. These were collective schemas and, therefore, some students did not have any category for a particular concept at all.
- When asked questions where the students could have used classroom knowledge they typically did not. Students typically reverted to personal driving experience or derived answers from observable content of the video. Over 63 combined instances of the students simply repeating the visual content or using data collected from the video to answer questions were observed and analyzed. This result suggests that proper ontological categories are not established well enough to support reasoning or are non-existent.
- There were 33 occurrences of admitted guessing sometimes supported with personal experience. This guessing behavior would also suggest that the knowledge structures developed in class are not strong enough to support reasoning about signalized intersection concepts or simply that these structures have not been established.
- There were 13 documented instances of clear misconceptions. Students confused highway level of service calculations with signalized intersection performance. Also, instances of students misconceiving the function of the controller and thinking it's more advanced than it is.
- Students struggled to connect traffic theory and actual traffic process. In several instances students were unable to make clear connections between class content to the traffic processes in the video. For example, a student could provide a graph of traffic flow but could not provide one for performance although the student could have used the same graph for both. Some of these graphs were developed on the spot using only their intuition and data from the video. Some of these graphs were almost 1:1 versions out of the text and not from a connection to the traffic process taking place in the video.

Conclusion 2

Student ontological structure of signalized intersection concepts is closely related to personal driving and riding experiences. The creation of ontological categories based on personal driving and riding experiences seemed to be stronger than the ontological categorization or knowledge structure of engineering concepts for signalized intersections. Evidence of such trends has been identified in previous research (1) (8).

Supporting data

- Interviewer observations indicated that students did not seem to use much classroom or engineering type knowledge for support.
- To reinforce the interviewers observations; there were 15 documented occurrences of personal driving experience used as support in students responses. These documented personal experiences were paired mostly within explanations of actuated controller function and left turn phasing descriptions. Both of these concepts also yielded a high percentage of the sample using these conceptual categories.
- Three particular categories yielded very high percentages of conceptual content compared to others. They were heavy vehicle behavior, timing plan design considerations for heavy vehicles, and the all-red safety interval. All three concepts were approximately 90 % or higher in the respective schemas.

  The connection to personal experience here is that there is very little time if any spent on these concepts in the introductory class with the exception of the all-red interval but in the scope of a semester it's still a small amount of time. Heavy vehicle interaction in the driving culture would likely influence the conceptual understanding of these concepts.

Research Directions and Questions

- The methodology presented in this study should be repeated on a larger sample that encompasses a larger geographical area and more universities. This should be done as a measure of validity to see if the findings can be repeated.

- Analyze the data from this study again but separate proper engineering vocabulary from accuracy of the responses to see if there is a difference.
- What are the expectations of educators who teach the introductory course? Are these findings acceptable?
- There is no other study like this to compare to so are these findings good or bad?
- What is the appropriate amount of time and pedagogy required for a student to restructure and reorganize categories from driver to engineer.
- How dominant is driving experience? How much does their driving experience interfere with reorganizing existing ontological categories or developing new ones?
- Can their driving experiences be efficiently used as a foundation for education?

The objective of the analysis of the second case study presented in Chapter 5 was to provide further evidence of a personal driver or non-engineer type knowledge structure of signalized intersection concepts amongst undergraduate civil engineering students. The study used data and results collected from the same exploratory case study explained in Chapter 4.

Working from conclusion 2 and the first research direction listed in the Chapter 4 summary above; this study makes a comparison between the conceptual accuracy levels of the student responses versus the engineering vocabulary levels used by the students.

These comparisons were made with the aid of a knowledge profile graph for each of the six schemas developed in Chapter 4. A knowledge profile, simply stated, is a graph that represents a score or level on the y-axis and a particular concept or schema of knowledge on the x-axis. These knowledge profiles presented in this study showed side-by-side comparison of accuracy and vocabulary levels for the same schemas of knowledge. An example knowledge profile developed in the study is presented in Figure 1.2.

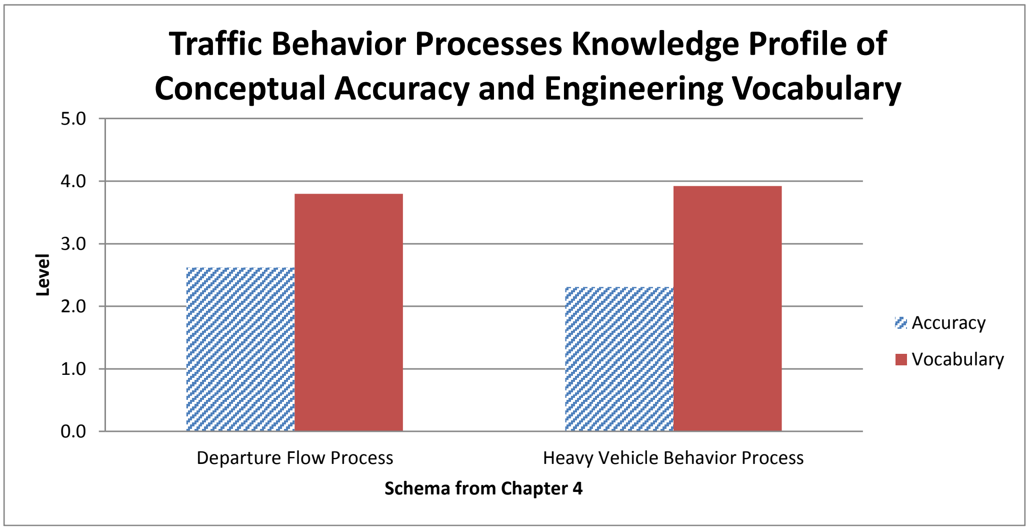


Figure 1.2: Example knowledge profile of traffic behavior processes schema from Chapter 4

The knowledge profile in Figure 1.2 shows scores for both conceptual accuracy level and engineering vocabulary level. The accuracy levels start at Level 1 which is defined as the expert level type of an answer with nearly 100% accuracy, rich in detail and go through Level 5 which is defined as very poor accuracy, very limited details, and not pertaining to the question asked. The vocabulary levels follow a similar scale with Level 1 being the expert level type of engineering vocabulary and going through Level 5 which is an answer containing mostly a driver like answer that contains no relevant transportation engineering vocabulary.

Prior to the development of the knowledge profiles, the data reduction (coding) process was validated because of concerns of only one researcher (Grad 1) reducing the entire data set. The process was validated with the help of three faculty experts and an outside university/program graduate student (Grad 2). The participants were briefed on how to assess the students in the same way Grad 1 did, then given two student interview audio recordings and transcriptions to assess. Then their assessments were compared with Grad1's assessments for the same students. The assessment comparisons were very similar to the Grad 1's results for engineering vocabulary. The accuracy validation had some differences and it was concluded that the accuracy level code definitions could use some refinement as well as further iterations (go through the assessment again) from the faculty experts was needed. The process was concluded to be valid for the study objectives.

The results indicated that the overall conceptual accuracy level average for the entire sample for all schemas was 3.2 and the engineering vocabulary level average was 4.0. All six schemas in the presented knowledge profiles showed that conceptual accuracy levels are higher than the vocabulary levels by approximately one level. Comparing these averages and trends with the results of the data validation experiment suggest that the trend in the data was valid, revealing how the majority of the students in the sample achieved basic conceptual accuracy, but they did so with very limited details and poor engineering vocabulary.

The results of this study showed a more generalizable measure that represented the entire student sample as opposed to just the 15 documented instances of personal driving experience found in Chapter 4 results. The results provide stronger evidence for further investigation with a much more focused and specially designed experiment to investigate more personal driver-like categories that would likely exist in novice transportation engineering learners. It was recommended that investigation should first focus on confirmation that these results be duplicated with another experiment.

Common Theme of Personal Experience

Although these chapters are standalone they do share a common theme in the results. The common theme is the presence of personal driving experiences in the student responses in the data. Personal driving experience was used by the participants as a means of support for their responses. Each of the papers viewed this phenomenon in several different frameworks of educational and cognitive science. Paper 1 used affordances, Paper 2 used ontological knowledge structure, and Paper 3 used knowledge profiles.

The evidence of personal driving experience found in student responses suggest that students were using personal driver-like categorization that seemed to exist at a higher priority than transportation engineering-like categorization. Evidence also showed that students were using driver-like vocabulary; they seemed to have a more conceptually accurate categorization of some processes.

Research in the field of conceptual change concludes that concepts and schema that are well established are difficult to rearrange, making conceptual change more difficult to achieve (12). The findings from this dissertation reveal how student's categorization of signalized intersection operations concepts is established from their perspectives as drivers and not as engineers. Chapter 6 discusses the implications of how students categorize and offers further suggestions on research directions.

CHAPTER 2: INCORPORATING TRAFFIC OBSERVATION INTO TRANSPORTATION ENGINEERING EDUCATION: POTENTIAL EFFECT ON CONCEPTUAL CHANGE

Introduction

Transportation engineering is a very complex engineering discipline as it pertains to a dynamic, observable, combination of human factors, social context, experiences, and engineering science. Conceptual understanding of this dynamic process needs to be viewed from a holistic view point rather than a single perspective of the system user. Students come to transportation engineering classes with a vast knowledge set that is gained primarily from their driving experience.

This pre-knowledge set can contain valuable insights for understanding different traffic phenomena, but can also contain some level of misconceptions that could lead to difficulties in practice. Traditional teaching methods, where theory is the major focus, lack in opportunities for students to use their pre-existing knowledge set to resolve misconceptions.

This chapter presents the results of investigating the incorporation of traffic observation into transportation engineering classes and its potential effects on conceptual change in undergraduate students. These effects were captured by a pre-semester and post-semester survey where a sample of student pre-knowledge was collected and compared to responses after the completion of the course.

Background

The work in this chapter uses the changes in affordances as a measure of conceptual change. Affordances are a view of perception and action that focuses on information that is available in the environment. They are defined as “any interaction involving an agent (student) with some other system, conditions that enable that interaction include some properties of the agent along with some properties of the other system” (13) (pg. 338). The student’s contribution in the interaction should be considered an ability or aptitude. Affordance and ability define each other, and one cannot be specified without specifying the other.

Affordance and abilities are bound by the constraint of the problem or task. For example, examine the task of a person navigating a horizontal curve. The affordance conditions include, but not limited to, “the shape and other mechanical features of the steering wheel, which is designed to afford rotary movement” (13) (pg. 339). The pavement markings afford the perceptual boundaries of the curve. In an engineering learning setting, an equation is the affordance for the ability to perform a calculation within the constraint of a solution process. Participants in conversation use terms and phrases as affordance to refer to objects, places, events and so on (13). Greeno (13), found that students use conceptual entities, operation of arithmetic, and symbolic mental representations from previous experiences as affordance conditions. Traffic observation, when appropriate, can then be used as a beneficial affordance condition to solve transportation problems encountered in practice.

Traffic observation is important to the traffic engineer because of the dynamic nature of the phenomena and processes taking place in the field. Traffic observation could be used in the classroom or laboratory to situate learning and give appropriate meaning to the static graphs and equations common in today’s traffic curricula. Traffic observation could help students develop new holistic conceptions of traffic phenomena and operations. In transportation engineering practice, the solution is rarely the single output of an equation or graph. Conceptual knowledge and observations over time become the affordance to solve broadly defined problems. Students need numerous, varied situated experiences to build a set of practical affordances for problems encountered in practice. Traffic observation can potentially achieve two goals in transportation engineering education: 1) Help students’ transition from the user perspective by showing them that traffic is more than a single experience 2) Help students resolve any misconceptions by showing them the dynamic nature of traffic in-step with theory. Now it’s time for the case study section describing the experiment and results.

Observation Based Advanced Signal Timing Class

A Federal Highway Administration (FHWA) project (9) was instituted at five universities to improve transportation engineering education by involving students in 10-week project-oriented courses. One of these courses was piloted at the University of Idaho during the spring semester of 2010. The course was offered to a sample of six students, including five senior undergraduates and one graduate student. The main objective of the pilot course was to test curriculum materials and collect data for analyzing student learning within the theoretical framework of conceptual understanding and situated cognition. The students were aware of the study, gave consent for their participation, and were actively involved in the data collection.

Course Description

The course was specifically focused on arterial signal timing design. The content was parsed in two units of actuated control, the first being isolated intersections, and the second being coordinated arterials. The course presents a unique situated context with limited lecturing and intense focus on traffic observation in a laboratory environment. A portion of the observation aspect was facilitated by the Mobile Hands-On Traffic Signal Timing Project (MOST) educational materials (10).

MOST is unique in that it uses observation to enforce learning by showing an actuated controller interface in step with simulated traffic. Students are able to monitor both the controller and simulated traffic operations simultaneously. This two-aspect learning condition allows students to observe the effects of different timing parameters on traffic flow in an interactive and real-time basis. In addition to the MOST materials, VISSIM microscopic simulation model was used as a tool to collect data, observe the effects of changes made to timing parameter selections, and use simulation animation and data output to propose and defend selections of parameters for their final design project. The following list contains all of the visual aspects embedded into the course design:

- Side-by-side observation of simulation animation of the corridor operations under two different control plans, one with bad offsets and one with good offsets. This allows students to observe and compare the traffic operations at all approaches in the two intersections included in the animation under the two control plans.

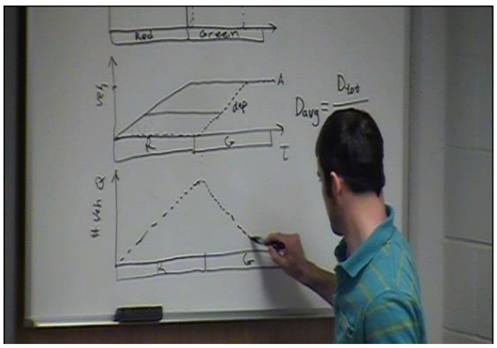
- Field data collection activities for comparison with idealistic traffic flow models.
- Approximately 25 activities that included the use of the MOST interactive microscopic simulation tool. The tool allows students to make changes to the signal timing parameters and immediately observe the change to the traffic operations

Students were required to complete two design projects; the first focused on an isolated intersection timing plan and the second focused on a two intersection coordinated signal system timing plan. All classes were designed to support the student's efforts to meet design criteria and complete their respective projects.

A typical class consisted of discussion of homework or pre-assigned group work with small group presentations of answers or findings from homework (image (a) Figure 2.1). A small lecture would follow that included learning objectives for new content, appropriate supporting theory, and instructions and methods provided to support activities. The rest of the class was usually group work activities that consisted of MOST exercises, micro-simulation observations, small quizzes, and calculation activities (image (b) Figure 2.1). Group work often involved the instructor or the teaching assistant answering questions and providing additional support (image (c) Figure 2.1). There were two design presentations where students provided support for their signal operation and timing parameter selections (image (d) Figure 2.1).

<table>
<tr>
<td>Typical Class Content</td>
<td colspan="2">

Discussion of homework or pre-assigned group work.
Small group presentations of answers or findings from homework, (image (a)).
Discussion of learning objectives for new content.
Mini lectures providing instructions, appropriate supporting theory, and methods.
Series of small group activities that included the use of MOST, micro-simulation observations, small quizzes, and calculation activities (image (b)).
Group work often involved the instructor or the teaching assistant answering questions and providing additional support (image (c)).
Group design presentations (image (d)).

</td>
</tr>
<tr>
<td>Images from Typicall Class Activities</td>
<td>(a)

(b)
</td>
<td>(c)

(d)
</td>
</tr>
</table>

Figure 2.1 : Typical class content and images from the advanced signal timing course.

Methodology

The goal of this research was to examine student learning in the above described course through the lenses of conceptual understanding and situated cognition. This study attempts to answer the following research question: Does traffic observation influence conceptual change? Conceptual change can be monitored by analyzing changes in student affordances. Affordances provide insights to students' conceptual understanding and therefore gains insights into the unique situation in which they learned.

The research design follows a longitudinal single case study approach which analyzes a single experiment over the duration of a semester (14). Single case studies are appropriate when the case represents a unique case or situation (14). The pilot course was chosen because of its unique aspects of instructional delivery and traffic observation. Single case studies are also appropriate when a longitudinal changes overtime are of interest (14). A framework of interest for this study is conceptual change and therefore duration of time is needed to observe change.

The single experiment is the course itself and measures are taken from student responses from a knowledge survey administered at the beginning and at the end of the semester. The survey was not a graded assignment and the students were aware of the research being conducted. Both surveys were identical, with two different objectives. The objective of the beginning-of-semester-survey (BOSS) was to capture and document initial affordances and to determine the kinds of pre-conceived conceptual transportation knowledge that students brought to the course from their introductory transportation engineering course and from their driving or riding experience. The objective for the end-of-semester-survey (EOSS) was to assess conceptual knowledge and affordances after the completion of the course, allowing for an assessment of conceptual change and changing use of affordances from beginning to the end of the course.

One line of questioning on both surveys revolved around a scenario of driving through a small two-signal corridor. Google Maps street-view images were used to illustrate the front and rear facing views from a vehicle at four locations in the corridor for a total of eight images. At each location in the corridor students were also given textual information regarding vehicle speed, signal wait times, and distances between signals to accompany the images. After reviewing the information the students were asked three questions and to provide written responses. Figure 2.2 shows the scenario information that the students received in the survey, the questions, and a sample of two Google Maps street-view images.

This line of questioning provides an opportunity to gauge the students' abilities of using traffic observation as affordance because it includes both visual and textual information. Student responses can be separated by the content pertaining to the use of text or visual observations as affordance. The types of questions also provide an opportunity to capture conceptual changes. There is no single answer for any of the questions and they are open-ended opportunities for the students to provide conceptual details regarding performance, quantification, and experience. The BOSS captured pre-conceptions prior to instruction and the EOSS captured changes in these pre-conceptions post instruction.

The data for this case study is focused specifically on the responses for the survey but there were more data and observations collected for further research. Every class was video recorded with separate audio recordings at individual desks. An in-class observer took notes, recorded observations, and estimated durations of activities for further revision of course materials. All students' written submissions, such as homework, tests, quizzes, in class activities, were collected and archived. Also two sets, pre and post, of one-on-one interviews with each student regarding their conceptual understanding of course content were conducted. The collected data is qualitative in nature and is said to contain richness and complexity that's beneficial for exploring new hypotheses and achieves deeper understanding of phenomena (11). For single case studies the results are not typically generalizable or transferable to broader populations. Instead the goal of a single case study is to generalize findings to theoretical propositions (14). In this case, the theoretical proposition is the answer to the research question aimed at conceptual change and the effectiveness of incorporating traffic observations in the course. The sample size of six students in the study is sufficient to answer the research question because it is 100% of the students taking the course and leaves no statistical gaps. To make a broader generalization to a population such as all civil engineering students; multiple case studies must be done (14).

The data was inductively coded according to common themes found throughout the student responses. The themes of interest for this research are types of affordances used by students and types of conceptual changes that might have occurred by the end of the course. The data was read through in several iterations looking for common, repeating types of affordances and conceptual changes across the sample. The approach outlined by Trochim (11) was used to quantify the affordances and conceptual changes and to analyze trends. The data was read through again and each instance of a particular affordance or conceptual change was assigned a value of one. After all responses were analyzed in this manner the total occurrences were summed and tabulated for each student and then for the entire class. By examining the changes in affordances and conceptual change from BOSS responses to EOSS responses gives insights to particular aspects unique to the class that was beneficial. Coding and data management was facilitated with the aid of the professional qualitative data analysis software Atlas TI.

<table>
<tr><td>Student Textual Information on Survey</td><td>Sample Google Maps Street View Images (2 of 8 images presented to students)</td></tr>
<tr><td>

Scenario Information

You are traveling west on 164th Street Southwest in Lynwood, Washington at a speed of 40 mph when you cross over Interstate 5. The view facing front, as you look out of your vehicle to the west, is shown in the figure. The view looking out the rear of your vehicle is shown in the figure (two accompanying images provided).
You proceed at your current speed for 256 feet to a signal at the I-5 off ramp that has a green indication (two accompanying images provided).
You continue at your current speed for 407 feet until you see a signal with a red indication at the intersection of 164th street and Ash Way. You gradually come to a stop at the intersection (two accompanying images provided).
You wait at the stop bar for 40 seconds then the signal indication turns green and you accelerate back to 40 mph hour and continue west on 164th street (sample of provided images are shown to the right).

Questions

Based on the given information in the text and pictures in the previous pages, answer the following questions. Use your driving experience to aid your answer.

How would you rate the signal timing performance for these two signals?
How would you quantify your experience through this two signal system?
What is the experience like for other drivers around you?

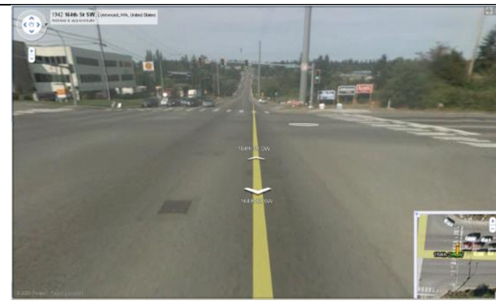
</td><td>


Figure Front view

Figure Rear view
</td></tr>
</table>

Figure 2.2 : Scenario information and sample Google Maps street-view images that students received in the survey

Study Findings

There were four common types of affordances and two types of conceptual change found across the student responses. The four types of affordances include observation information, text information, personal insights, and personal perspectives. The two types of conceptual change include shortened responses and the change in response. They are presented in sets according to their association with each other. Each set of affordances and conceptual changes are defined and explained with examples from the student responses. Figure 2.3 shows a sampling of BOSS and EOSS responses to provide examples of each type of affordance and conceptual change over the duration of the semester. Next the total tabulated occurrences of each type of affordance and conceptual changes are presented and trends explained. From these trends, the research question was answered by analyzing the trends of the use of affordances and conceptual changes. The trends will give insights regarding the particular aspects of the course that influenced these trends.

Types of Affordances

The first set of affordances relates directly to student use of observation or textual information as affordance. An observation is defined as any part of the response that can only be derived from the images provided in the survey. Text information is defined as any part of the response that is derived from the text provided in the scenario information. For example, Figure 2.3 part (a), shows that Student1's BOSS response uses "40 second", " red", "green" and "400' down the road" for affordance in the response. The distance, time, and signal indication information are only found in the text and it affords a portion of the students reasoning. For this response Student1 does not use any visual observations from the images as affordance. Student1's EOSS response shows two instances of textual information and two instances of observation as affordance. The two observations are "random car", where the student observes his position and sequence relative to other vehicles and "platoon arrives", where the student is expressing that the vehicles behind him (image 2 in Figure 2.2) are a platoon of arriving vehicles.

Text information also had to be interpreted by meaning. Looking at Student6's BOSS response, Figure 2.3 part (b), shows to instances that were interpreted by meaning. When Student6 says, "make it through all at once" implies that the stopping information was used from the text and "took a while" implies the 40 seconds of wait time. Student6's EOSS response shows another instance of text that had to be interpreted by meaning for "have to stop".

The second set of affordances relates to students using their pre-conceptions from previous experiences as affordance. These types of pre-conception affordances were given the names of personal insights and personal perspectives. A personal insight is defined as any information that a student would add to the response that did not originate from the text or the images. Using Student1's BOSS responses as an example, part (a) and (c) in Figure 2.3, it's clear that the majority of the responses do not originate from either the text or the images, rather it is a description of what could happen. These types of personal insights relate to previous driving experiences and the language is rather driver like. For example, part (c) of Figure 2.3, Student1 uses the phrases "hit the end of green" and "hitting the end of red". This is the type of language that might be expected in casual conversation between drivers. Clearly the student is talking about components of progression, which does not relate to the question about quantification, but it lacks engineering terminology. Other types of personal insights were instances of information that did not exist, like right-turn-on-red and saturation flow rate information. These types of personal insights are most likely related to a previous transportation courses or driving experience.

Personal perspectives were a special type of pre-conception that were common in the responses and is defined as the use of language that conveys the personal feeling or intentions of themselves or other drivers. Looking at Figure 2.3 part (d), Student2's BOSS response displays two instances of personal perspective with "in a hurry" and "road-rage" and two for the EOSS. Personal perspectives also most likely derive from previous experiences and attitudes from the driving culture. This is a pre-conception that may be a reflection of their own perspective so they perceive that other drivers feel the same way. Additionally, their personal perspective of a single experience of 40 seconds of delay prompted these perspectives as affordance. This is quite different than the engineer, who is less concerned about one data point and more concerned with using averages of many drivers over time, in all directions, during peak periods as affordance to make adjustments to timing plans.

Types of Conceptual Change

To assess conceptual change, differences in responses over the duration of the semester were examined. From the literature review it was stated that conceptual change is the difference in pre-conceptions or misconceptions over time. Therefore, the entire response will be analyzed for differences from BOSS to EOSS rather than looking for specific affordances. Although a difference in affordance is a part of the conceptual change. The two types of conceptual changes found are shortened responses and change in response

Shortened responses are defined as the relative reduced number of words or refinement of response. Again, using Student1's EOSS responses as an example, part (a) and (c) in Figure 2.3, shows that both responses are shortened and refined. In part (c) shows the response going from a grandiose personal insight scenario to a discrete explicit quantification of delay. This shows conceptual change from being a personal driver like justification to a conception that this scenario is quantified by delay. Shortened responses were also the result of improved vocabulary elements. Looking at Student6's responses, part (b), shows, "intersections all at once" changes to "coordinated". This shows that the student initially had conflicting driver perspective information about coordination but now it has a name. This shows that his pre-conception of coordination remains intact but the change comes in the form of proper engineering vocabulary.

(a) Student 1 Responses for Question 1

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "I would rate the signal timing performance rather low. If signals are timed appropriately then a car that passed through the previous light on a green shouldn't have to wait at a light 400' down the road on a 40 second red. However, if the vehicle passed through on the end of green in 400' you might expect to sit @ a 40 seconds red."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* – "Not sure, not enough information to determine, however it seems like you are a random car that arrived on red, but the light changes green when the platoon arrives so it might be performing well its just too hard to determine."

(b) Student 6 Responses for Question 1

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "Not very good because I did not make it through the intersections all @ once. Also, when I did stop it took a while for the light to turn green again."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* – "Its ok, we are on the main road & the lights should be coordinated so we don't have to stop or have little delay like 10 sec."

(c) Student 1 Responses for Question 2

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "My experience was not that great. The fact that I had to wait on a 40 sec red was not pleasing. However, if I hit the end of the green then hit the beginning of the red then the experience is expectable &just. If I had the red after hitting the beginning of the green then the experience is poor & new timing needs to be considered."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* – "Average delay per signal = 20 seconds. A delay of 40 seconds is bad."

(d) Student 2 Responses for Question 3

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "It would be about the same for the other drivers unless they are in a hurry for some important reason and don't want to wait 40 seconds. Road rage could ensue."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* – "The other drivers in my direction arrive when the light turns green so they are prob(ably) happy. The minor street was served so they are ok with that but 40 sec. seems long for the minor street service"

Figure 2.3 : Sample responses and examples of common themes

Change in response codes were assigned to responses that displayed change in performance, quantification, or experience from BOSS to EOSS. Examples of change are present in the all of the responses in Figure 2.3. Student1 going from “rather low” to “not sure”, Student6 going from “not very good” to “it’s OK”, Student2 going from “road rage” to “happy”. Their change in response indicates a new changed concept of performance, quantification, or experience. Also, examine Student1’s EOSS response in part (a), where he states that there is “not enough information” to gauge performance, which implies a conceptual change from using a single data point to recognizing that more information is required to make an informed decision. By using, “random car”, Student1 now recognizes the stochastic nature of traffic flow from the many observations of traffic made throughout the semester and has displayed conceptual change. Additionally changes in response were identified by the difference in choice of affordance. Student1’s BOSS and EOSS responses in part (a) and (c) of Figure 2.3, show he reduces the affordances of personal insights, personal perspectives, and use of text information while showing an increase in observations. This shows that the students’ entire concept has changed.

Trends

Upon completion of coding in the previously described manner some interesting trends were found. Figure 2.4 shows the total recorded codes for all students for each respective question. Part (a) shows the affordance set of observations and text, part (b) shows the affordance set of personal insights and personal perspectives, and part (c) shows the conceptual change set of shortened response and change in response. A positive number in the difference column represents an increase of the respective theme and a negative number represents a decrease.

(a)	Observations			Text Information		
	BOSS	EOSS	Difference	BOSS	EOSS	Difference
Question 1	6	11	5	15	6	-9
Question 2	0	2	2	6	9	3
Question 3	5	13	8	3	3	0

(b)	Personal Insights			Personal Perspectives		
	BOSS	EOSS	Difference	BOSS	EOSS	Difference
Question 1	2	0	-2	0	1	1
Question 2	4	0	-4	3	0	-3
Question 3	4	1	-3	7	2	-5

(c)	Shortened Response (EOSS)		Change in Response (EOSS)	
	Yes	No	Yes	No
Question 1	6	0	4	2
Question 2	3	3	5	1
Question 3	3	3	5	1

Figure 2.4 : Total occurrences of affordances and conceptual changes for student survey responses

Examining the observation and text set in Figure 2.4 part (a), there is an obvious increase in the use of traffic observation as an affordance from BOSS to EOSS. Results for questions 1 and 3 show increases in traffic observation. It is expected that observation in question 2 would be limited because the question specifically asks for quantification but the two instances of observations recorded were not specific to their experience and were directed to other users in the system. This still shows that students want to use the information available to them in the images rather than the text. Examining the theme of text shows that students are slightly more reliant on text information in BOSS responses and less reliant in EOSS responses. Again the increase in the use of text in question 2 is expected because the information regarding quantification can only be found in the text. In BOSS responses two students failed to quantify their experience for question 2 and in the EOSS responses, all students used the 40 seconds of delay as quantification and some additional measures such as number of stops and cycle failures. The overall trends expressed in the observation and text themes indicate that students in this class increased their use of traffic observation as affordance and reduce the use of the text information.

The themes of personal insights and personal perspectives, Figure 2.4 part (b), show that students use these themes in BOSS but almost non-existent in EOSS responses. Personal insights and personal perspectives were not particularly important to the students for question 1 with only a small number of insights coded. Comparing this to questions 2 and 3 shows much higher use of these affordances. This says that initial quantifications and other driver experiences are rooted in personal insights and personal perspectives. This is showing conceptual change of quantification and experience. Showing they change from a driver like view with many insights and perspectives in the BOSS to more explicit, using engineering terms, responses that show true quantification and accurate observable experience. Most interesting here is the large number of personal perspectives found in question 3 BOSS responses. This suggests that students' pre-conceptions about other drivers in the traffic stream are gauged by feelings. In comparison to EOSS these personal perspectives are not as important for affordance as the relevant engineering traffic information.

Shortened responses and changed responses, Figure 2.4 part (c), were very common in the results. The majority of shortened responses were due to students using correct and improved vocabulary. Improved vocabulary elements are conceptual change because in the majority of BOSS responses, students could describe elements of coordination in terms of a driver but in EOSS responses were more defined using engineering vocabulary. The change in responses over the duration of the semester was large with almost the entire class changing their responses on questions 2 and 3.

Effects from Signal Timing Course

As explained in the trends section, the data show that students decreased their reliance on the text information as affordance and increased the use of traffic observation as affordance. This is a significant finding because it shows that the delivery method of the course can achieve the goal of improving traffic observation abilities. This also raises questions of; why or how did the observable information in the images increase as an affordance? This increase is likely due to the large amount of traffic observation done in the class and is expected because the unique aspect of this course uses traffic observation as a provided affordance for learning to give meaning to static graphs, charts, and equations. Letting the students watch the dynamic nature of traffic flow and actuated signal timing processes accompanied by appropriate theory led them to be more traffic observers than they were static data interpreters. The in-class observer witnessed students becoming more confident, comfortable, and fluent when observing traffic, interacting with classmates during observation activities, and during design project presentations. Since there was a large amount time between survey administering, students may have also improved their traffic observations with every instance of personal travel. This is still a byproduct of the class where students can make comparisons with their teachings and learning.

Some students were more pronounced in their observation abilities and some were not as pronounced. For example in Figure 2.5 part (a) we see that Student2 uses 1 instance of observation in his BOSS response and increases to 4 observations in his EOSS response. This was typical of Student2 showing the most conceptual improvement and use of observation as affordance in the survey responses. Looking at Student5's response, Figure 2.5 part (b), shows the opposite trend where he made two observations in the BOSS and only 1 in the EOSS. The benefits for Student2 are obvious that he can analyze the system for its operation rather than the mere static output of delays. He can now analyze and make adjustments to timing parameters based on observations and static output.

As stated in the literature review, students are most likely to hold pre-conceptions from the viewpoint of being in the vehicle as opposed to watching the intersection operate cycle after cycle. This explains the trends found in the affordances of personal insights and personal perspectives in the BOSS responses. Personal insights were very important to Student1 and Student3, Figure 2.5 part (c) and (d), showing typical added information to their responses. Another example of Student1 was shown in the theme descriptions section Figure 2.4 part (a). Personal perspectives were important to all students in their BOSS responses. The reduction in these themes is a direct result of the class but not necessarily a result of the unique situation that is presented to the students. Students taking a more traditional lecture course may show the same reduction in their personal language over the duration of a semester. But the noticeable reduction of insights and perspectives in conjunction with increased observations indicate the unique situation of this course may have influenced the reduction. By observing traffic the students see many vehicles over time, cycle after cycle, on all approaches. One particular vehicle experience becomes less important when many experiences are being averaged over the period of an hour at peak volumes. Therefore the perception that the students have in the survey changed because their conception has changed from a personal situation to an engineering situation.

Shortened responses were said to be mainly caused by improved vocabulary. This is a result of the combination of many learning activities during the semester including observation activities. Looking back at
Figure 2.1 image (a), the student is participating in a small presentation of homework findings. Here the student must use proper vocabulary to convey results. Images (b) and (c) show the typical small group setting where the students were engaged in an observational activity. They could verbalize terms with each other and be engaged in conversations with the instructor or teaching assistant that would use proper vocabulary. Finally image (d) shows the students participating in their final design project presentation where proper vocabulary must be used to convey results. So the aspect of the class that improved vocabulary was repetition with many opportunities to use proper vocabulary by writing and speaking in step with observation. In comparison to a traditional lecture type course where vocabulary may only come from reading, taking notes, and listening to the lecturer. Traditional lecture courses do not typically reinforce vocabulary through activity. Some students showed increased vocabulary but did not reduce the length of their responses. For example, Student4 (not shown for length), was very good at providing very lengthy responses.

(a) Student 2 Responses for Question 1

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "It seem that the stop (red light) cycle at second signal was a little long because of the low volume of traffic. Waiting 40 sec at a red light when there weren't many other cars in the intersection seemed unnecessary. Overall I would give them an average rating. It would be better if they were censored for more efficient use."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* - "The signals worked ok. It looks like I was a lone car and the second intersection gap out in front of me. Then when the platoon of vehicles behind me the light turned green. Probably because of the offsets for the platoon."

(b) Student 5 Responses for Question 1

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "The signal timing is pretty good. The cars from the first light reach the second just as it turns green. The only problem is that it dosent allow time for the cars at the 2nd intersection to leave before the cars from the previous signal reach it. Which impedes the through traffic."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* – **"**Mediocre, the platoon of cars arrive earlier then the light turns green. I experienced a high delay and was not happy"

(c) Student 1 Responses for Question 3

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "Other drivers around me are more than likely not educated in traffic engineering, so they might not analyze the intersection like I would. The typical driver would probably not ever consider the red, or get upset& think they must have bad luck, hitting all reds."
- *End-of-Semester-Survey (EOSS) (5/6/2010)* – "Normal, seems like the light turns green when the other drivers in the platoon arrive."

(d) Student 3 Responses for Question 3

- *Beginning-of-Semester-Survey (BOSS) (1/19/2010)* – "Equally stressful. The proximity of the lights means vehicles may back up into the previous intersection if stopped at the second intersection"
- End-of-Semester-Survey (EOSS) (5/6/2010) – "High queues, long travel time**"**

Figure 2.5 : Additional example responses for explanation of trends

Conclusion

The findings from this case study demonstrated that the students increased their use of traffic observation as an affordance condition and it's likely a result of the learning environment presented to them in the signal timing course. The increased use of traffic observations in the course was accompanied by an increase in changed responses which implies that traffic observation has influenced conceptual change. The unique aspect of the course that made this possible was the emphasis of traffic observation through the use of, side-by-side comparison of timing plan changes, MOST training materials, and VISSIM micro-simulation. Findings also show that students extensively used pre-conceptions that were personal in nature as affordances to answer in the BOSS. Such personal pre-conceptions are almost non-existent in the EOSS. This finding, again, shows a major conceptual change where personal insights and perspectives becomes a less dominating portion of their understanding of the traffic phenomena. The many observations over time show the students that one experience is a very small portion of the larger process. Students also showed more improved vocabulary in their EOSS responses. The trends in increased vocabulary were the result of students being involved in group observation activity.

CHAPTER 3: EXPERIMENT AND DATA COLLECTION PROCESS

The following chapter summarizes the experiment and data collection process used for both analysis's completed for the second case study presented in Chapter 4 and Chapter 5.

Data Collection Process

Specifically, a 3.5 minute video of an actuated signalized intersection in Lewiston, Idaho was used to facilitate questioning with visual prompts from the traffic behavior. A video was chosen for its ability to show various traffic processes taking place in real time field conditions. The video is completely void of calculations and allowed for a more conceptual type of discussion with students. A screen shot from the video is provided in Figure 3.1. The intersection volume level provided enough traffic for the demand responsive timing processes to be separately observed without continuous cycle failures and maximum green terminations. There was sufficient information in the video to ask questions about the following processes:

- Actuated controller operation/function
- Left turn phasing
    - Protected
    - Permitted
    - Protected/Permitted
- Departure flow/queuing theory
- Heavy Vehicle Effects
- Safety (Clearance) Intervals
- Intersection Performance

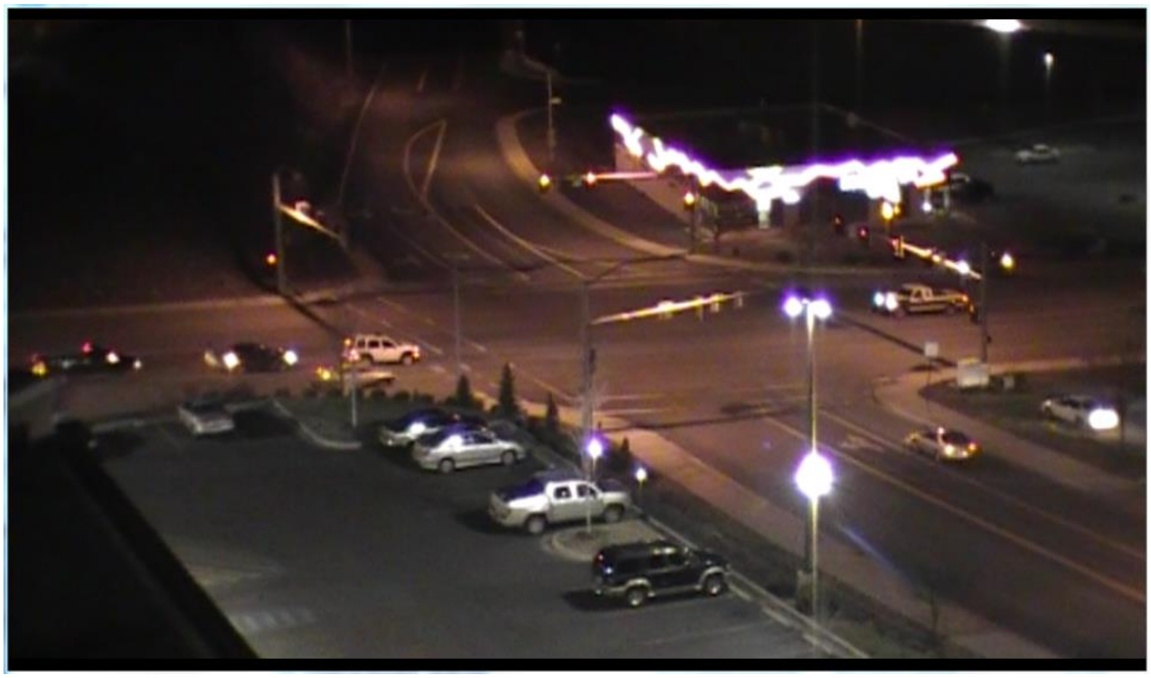


Figure 3.1 : Screen shot from the video used during the interview

Student Sample Characteristics

The sample consisted of 27 paid volunteer students from the civil engineering programs at the University of Idaho and Washington State University. Table 3.1 shows the sample characteristics of gender, class status, and performance ranking. The performance rankings, in Table 3.1, are based on information provided by the respective instructors and ranked 1 through 4. Rank 1 students are high performing and receiving an A grade, Rank 2 are above average performance, Rank 3 are average performing, and Rank 4 are failing or poor performing students. The students had little to no prior experience in transportation engineering practice or education other than the geometric curve design section of their introductory surveying class.

Table 3.1 : Table showing the characteristics of gender, class status, and performance rank of the student sample.

		Gender		Class Status			Performance Ranking			
	Participants	Male	Female	Graduate	Senior	Junior	Rank 1	Rank 2	Rank 3	Rank 4
Washington State University	16	11	5	0	5	11	7	6	3	0
University of Idaho	11	6	5	1	2	8	6	3	2	0
Total	27	17	10	1	7	19	13	9	5	0

Interview Questions

The interview questions were developed from the observable content of the video. Questions were focused on core signal timing concepts used in signal timing plan design. The questions were open-ended questions without a discrete answer and were intended as a starting point to further provoke conceptual content from the student. Since this study is not a direct assessment of the introductory course and therefore questions may not directly relate to introductory class content. Three of the questions are directly related to basic traffic flow, basic performance, and graphs that are taught in the introductory course. Four slightly advanced but basic conceptual questions related to controller function, left turn phasing, and vehicle effects on timing plan. These concepts are briefly covered in the textbook but little attention or focus is typical in the introductory class.

For example most introductory courses focus on fixed time control and do not focus much, if any, effort on actuated control. This study captures a knowledge state prior to advanced classes so questions directed towards actuated control will reveal categories obtained in the introductory course or life experiences. For example a student could use knowledge gained from queuing theory instruction to support their answer or they could give a more general personal driving experience supported answer. The interview protocol is provided in

Question	Intended focus concept elements
1. Why/How does signal turn yellow at 00:15/00:16?	This question was meant to extract conceptual knowledge regarding controller operation and signal phase change.
2. Why do these south bound left turn vehicles go before the north bound through vehicles at 00:23?	This question was meant to extract information regarding left turn treatments and their design concepts.
3. Notice that the north bound through green starts at 00:36; what can you say about the flow of vehicles across the stop bar? Could you represent the flow of vehicles with a chart or graph? (Follow up question was to ask which part of their graph represented flow.)	This question was meant to extract student conceptions about departure flow and to evaluate a student's ability to graph and understand which parts of the graph applied to departure flow.
4. A tractor trailer combination is visible at the east approach at 00:56. What effects do these types of vehicles have on signal timing?	This question was meant to extract student conceptions about heavy vehicle behavior at intersections and how this behavior affects the signal timing plan.
5. A vehicle leaves the east approach heading west at 01:10 with a yellow indication. In terms of signal timing what safety settings are set to ensure the vehicle clears the intersection safely?	This question was meant to extract student conceptions regarding the change and clearance intervals.
6. At 01:18 the SB phase starts with the SB left turn going before the NB through. At 01:31 the NB phase shows green and the vehicles execute their movements. Why are the SB through vehicles allowed to continue and the SB left turn have to wait for a gap?	This is similar to question two because it concerns left turn treatments, but question six specifically focuses on protected/permitted behavior and is meant to extract design concepts of why that particular treatment exists.
7. The north approach gets a red indication at 01:51. Can you produce a chart or graph that represents the performance or experience that the through vehicles encounter for a complete cycle? (Follow up question was to ask which part of their graph represented performance.)	This question was meant to extract student knowledge and perception of signalized intersection performance, and evaluate their ability to graph and make connections between what they see and what they produce in the graph.

Figure 3.2, showing each question, the approximate time in the video where the traffic behavior occurs, and a description of the intended concept focus.

Question	Intended focus concept elements
1. Why/How does signal turn yellow at 00:15/00:16?	This question was meant to extract conceptual knowledge regarding controller operation and signal phase change.
2. Why do these south bound left turn vehicles go before the north bound through vehicles at 00:23?	This question was meant to extract information regarding left turn treatments and their design concepts.
3. Notice that the north bound through green starts at 00:36; what can you say about the flow of vehicles across the stop bar? Could you represent the flow of vehicles with a chart or graph? (Follow up question was to ask which part of their graph represented flow.)	This question was meant to extract student conceptions about departure flow and to evaluate a student's ability to graph and understand which parts of the graph applied to departure flow.
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6. At 01:18 the SB phase starts with the SB left turn going before the NB through. At 01:31 the NB phase shows green and the vehicles execute their movements. Why are the SB through vehicles allowed to continue and the SB left turn have to wait for a gap?	This is similar to question two because it concerns left turn treatments, but question six specifically focuses on protected/permitted behavior and is meant to extract design concepts of why that particular treatment exists.
7. The north approach gets a red indication at 01:51. Can you produce a chart or graph that represents the performance or experience that the through vehicles encounter for a complete cycle? (Follow up question was to ask which part of their graph represented performance.)	This question was meant to extract student knowledge and perception of signalized intersection performance, and evaluate their ability to graph and make connections between what they see and what they produce in the graph.

Figure 3.2 : Interview protocol questions and intended focus concept

Interview Process

Each interview took approximately 30 minutes to complete. Students were asked to watch the entire video to get comfortable with it, get directionally oriented, and make sure they could identify signal indication colors. After the initial viewing, the video was restarted and the focused questioning took place. The interviewer would stop the video periodically so the student would have time to answer. Figure 3.3 provides a typical sequence of questioning for Question 1 showing how the initial question was a starting point to gather conceptual content from the student. For example, in Question 1, if a student mentions something about the intersection “sensor,” the student would then be asked to provide further details on what they meant by sensor and therefore gather more conceptual details.

The qualitative data set consists of approximately 13 hours of audio recordings, and the transcriptions of the interviews amounted to a 322 page document of 82,000 words with 53 graphs and sketches to analyze.

Interviewer: So now, we'll go back through and I'll ask you some more focused questions about what's going on there. Keep an eye on this approach here. It turns green. One vehicle makes a through movement. One executes a left turn. The next vehicle comes along, makes a left turn. Turns yellow. Now it's red. Pause that. Can you explain how or why or the process of how that changed from being green to turning red and now is going to give service to one of these approaches?

Participant: Can you repeat that one more time?

Interviewer: Can you explain how or why that changed from green to red? Explain the process.

Participant: So why it changed from going green east and west to going red.

Interviewer: Yes.

Participant: Well, there is no more queue here so I assume the light-- I'm not sure if it's ran by sensor or ran by time but it's going to assume, okay, the queues ended for east and west and now there is a queue starting to form on the north-south bound so we're going to turn the east-west red and get ready to go green on north and south.

Interviewer: You say it could be on a time or a sensor. When you say sensor, what do you mean?

Participant: Possibly there might be some sort of, I don't know, some sort of device that detects if a car is in a line on the east-west.

Interviewer: Do you have any ideas of how that would work?

Participant: Not particularly. I know I have seen some intersections before so I know that they have them. You'll pull up. It will be a side street on a main highway late at night and the main street or the main highway is getting a full green pretty much nonstop. Then you pull up on the side street and it'll go red on the main highway so that the vehicle on the side street can pass through. Possibly something in the road or some sort of sensor detector on the lights itself.

Interviewer: What did you mean by "timer"?

Participant: The light's automatically timed to allocate a certain amount of time going one direction. Allocate a certain amount of time going east and west and allocate a certain amount of time, I noticed, right after this it will go green with protected left hand turns. So, the southbound you can either go through or you can take a left hand turn protected so these guys are still stopped, I think, if I recall correctly. So a certain amount of time will be allocated to that green movement, protected left and then the protected left will go red, the through traffic with continue and a certain amount of time will be allocated to both north and southbound being able to pass through.

Figure 3.3 : Transcription example of questioning sequence for question 1.

CHAPTER 4: STUDENTS' KNOWLEDGE STRUCTURE

Introduction

The purpose of the second case study was exploratory and aimed at generating hypotheses, theoretical propositions, relevant questions, and research directions to focus future research to aid in the development of better curricula and instruction for transportation engineers. An exploratory case study is appropriate for developing hypotheses and research directions (14). The analysis documents the student knowledge structure of signalized intersection concepts after completing the introductory transportation engineering course.

A students' knowledge structure, or prior knowledge state of signalized intersection concepts after completing the introductory course, will be the knowledge base they have when entering advanced courses or transportation engineering practice. The prior knowledge structure is "all knowledge learners have when entering a learning environment, which is potentially relevant for constructing new knowledge" (15).

The study of the structure of knowledge, or in cognitive science terms "ontology", involves looking into the hierarchal structure of knowledge and the implications it has on conceptual change. A concept is a subset or piece of this hierarchal knowledge structure. Conceptual change is the structuring and restructuring of hierarchal categories of knowledge and is "an essential contribution to an effective diagnosis and support of a students' learning process" (16).

Although inferences can be made from the results presented in this chapter, this work is not intended to be a direct assessment of the introductory transportation engineering course. First the exploratory case study research design is not appropriate to make that type of assessment. A larger sample from a broader geographic area encompassing many universities would be appropriate to make a generalizable assessment of the course. The second reason is that this study is focused on signalized intersection and core signal timing concepts. The introductory course is a broad sampling of many fundamental transportation engineering design concepts. Therefore this study is focused on a small portion of concepts presented in the course.

Additionally, some of the questions posed to students in this study are a slightly out of a familiar context and slightly more advanced than they might be used to. For example the introductory class primarily focuses on fixed time control concepts for signalized intersections but some of the questions presented here are focused on actuated control. Other questions in this study are directly focused on concepts typically taught in the introductory course such as traffic flow.

The results of this analysis show how the novice transportation engineering student classifies and organizes their knowledge after completing an introductory transportation engineering course. By examining the organization and structure of knowledge leads to questions and hypotheses that focus research of other design. New directions and focus of research will benefit both educators and transportation engineering practitioners interested in developing new curricula.

Background

Structure of Knowledge (Ontology) Overview

Ontology is the philosophy of being, what exists, and how information is categorized. The theoretical assumption of ontology considers prior knowledge as being organized in an interrelated hierarchal structure (16). Ontology, thus, should be viewed as structured, organized, and/or categorized thinking. Prior research has identified three distinct ontological categories learners use to organize or categorize their thinking (see Figure 4.1) (12). The details of these specific deeper categories become an issue of how the learner develops these categories based on their own unique experiences and perspectives of knowledge and how knowledge is obtained (12).

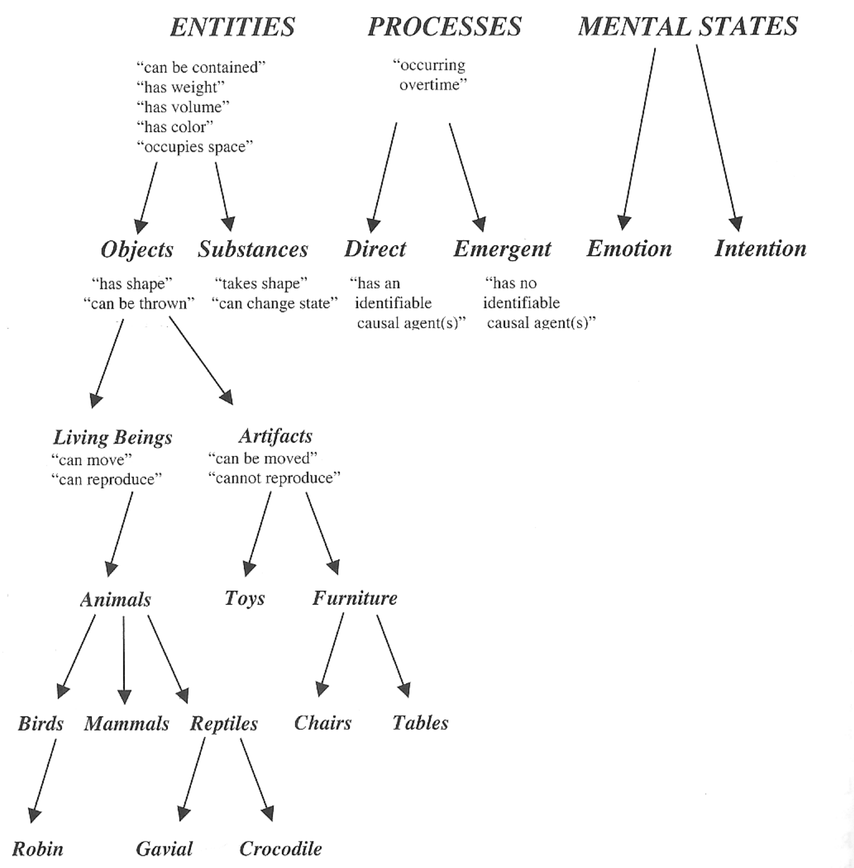


Figure 4.1 : Distinct hierarchal ontological trees from Chi (12)

Implications of Structured Knowledge in Learning: Expert and Novice Learner Behavior

Experts and novices use their respective ontological categories in different ways based on their level of experience with a respective concept. Novices use a "bottom up" approach (Figure 4.1) by establishing isolated unorganized categories first. As novices become experts, they move to a "top down" approach, developing "schemas" or "chunks" of interrelated and organized categories that are higher on the hierarchal tree (17) (18). For example, an expert may infer that robins lay eggs even if they have never been told this fact (17). They infer this because they have developed larger interrelated schema of birds and bird characteristics. Therefore, since a robin is a bird the expert can infer that it can lay eggs. Novice learners, however, may only be able to infer that a specific type of bird lays eggs and not others because they have not developed a larger schema of birds and bird characteristics. The individual's construction of these isolated categories is important to the development of schema of a higher order and is paramount to conceptual change.

Conceptual Change

When novice learners such as students are presented with new information, they attempt to apply it to existing schemas or reorganize and redefine these existing schemas (2). If their pre-existing schema is in conflict with new information, but they are able to reorganize the schema to include this new information, conceptual change is said to have taken place (12). Because prior knowledge states and respective schemas are dynamic in nature, learning occurs as a successive transition between knowledge states. A well-structured prior knowledge state and schema will enhance the acquisition of new knowledge (16). If the existing schema is not well organized, poorly structured, or flawed, it is difficult to achieve conceptual change (12). This research assembles collective process schemas derived from responses to questions regarding signalized intersection processes from a sample of engineering students.

Qualitative Methodology, Data Collection Process, and Data Reduction

Students were interviewed who had just completed an introductory transportation engineering course at two universities. Students first watched a video of an actuated intersection operation before being asked questions specific to the content of the video. Interviews were audio reordered and transcribed. The transcriptions were then analyzed for conceptual content and coded to identify ontological categories and then assembled into collective schemas.

Data Reduction

The qualitative data set consists of approximately 13 hours of audio recordings, and the transcriptions of the interviews amounted to a 322 page document of 82,000 words with 53 graphs and sketches to analyze. The data were coded by following an approach outlined by Trochim (11), and used by Cooley (8), where the data were read through while listening to the audio in several iterations looking for portions of the student responses that could be considered a category in a process schema. A new code was developed when students would provide a new category or an established code would be assigned if the student answered similar to other students. These codes were then tabulated for the percentage of the sample that had a particular code assigned then these codes were assembled into small schemas that show the collective structure for the sample. These codes were managed and tabulated for analysis using qualitative data management software (Atlas-TI).

Because the aim of this research was not to assess conceptual accuracy or transportation engineering vocabulary level but rather to extract the content that might be considered a category. Therefore, student responses were coded by determining the identifiable content that could be considered a category of signalized intersection knowledge. For example, in Figure 3.3, where the student is talking about a "sensor" or "some sort of device that detects" and then describes and experience where he saw the demand responsive process from personal experience, the response would be coded as an "overall actuated process explanation". The student is unsure and does not use correct vocabulary, but there are enough actuated process elements existing in his mind and is a potential category. Additionally the student would receive a code of fixed time process when asked to explain what he meant by "timed". The categories for this student can't be taken much further because he does not provide much detail about basic fixed time controller function. He mentions vague ideas related to detection but does not identify type or function so it's just considered to be part of the actuated process or in the area of demand responsive control. If a student mentioned a specific type of detector then the respective code would be assigned. The codes were not determined before the coding process and are presented as findings in the results section.

Personal Driving Experience, Misconceptions, Visual Based Information, and Student use of Graphs

In addition to the category codes, there were codes assigned to responses that exhibited a specific answering behavior. These behaviors were used for supporting the students' logic or reasoning. These behaviors dealt with personal experiences, guessing, misconceptions, and how the student used the visual information from the video.

Figure 4.2 explains each of the behaviors.

Response Behavior	Code	Definition
Personal Experience	PERSEXP	Responses contain a personal experience or explained driving experience ("how it usually works" "what I've noticed here in town")
Admitted Guessing	GUESS	Responses contain an admitted guess. The student had to say a statement similar to "I guess" or "I'm guessing" to receive the code.
Misconception: Highway Level of Service	HWLOS	Responses contain concepts that pertain to highway level of service calculations
Misconception: Controller technology more advanced	CONSMRT	Responses contain speculations of more advanced controller technology. For example one student thought that the controller was capable of identifying specific vehicles and vehicle types.
Repeating Visual Information	VIDRPT	Responses contain content where the student is merely repeating the visual information in the video for evidence supporting their answer. Instead of answering they just repeat the visual sequence of events as they appear in the video.
Collecting Data from Video	VIDAORD	Responses contain evidence that the student is using visual information from the video to support their answer. This is noticed when the student attempts to draw the attention of the interviewer to the screen. They collect data from the video in the form of volume, arrival order, signal indications, or similar data collections to justify reasoning.

Figure 4.2 : Response behavior definitions that were commonly used to support the logic or reasoning for student responses.

Examining the response in Figure 3.3, a code of PERSEXP was assigned because the student describes a personal driving experience where he notices that his presence at an approach seemed to affect phase change. A code of VIDAORD was assigned when the student verbally expresses to the interviewer that there is “no more queue here” and “now there is a queue starting to form on the north-south”. The student is directing the interviewer’s attention to the visual information as sort of a data collection to support his reasoning.

An example of the VIDRPT code is presented in Figure 4.3. This was a unique and interesting theme where students would simply repeat the visual sequence in the video for supporting their answer. Instead of answering the question, they simply thought the sequence of vehicles was the answer. This could have been a stalling tactic to slow down the interview for adequate thinking time to understand the question, but it was definitely a re-occurring theme with many students.

For questions 3 and 7, students were asked to develop graphs. There were a set of codes developed for these questions as well. A code was assigned for a certain type of graph the students would produce. Figure 4.4 shows examples of the different types of graphs students would typically produce. An intuitive graph is defined as not originating from the textbook or class lectures. It would appear as if the student was using his/her observations and intuition to create a new graph for the first time. The text/class graph is defined as looking very similar to a graph from their textbook or information they might have received in lecture. The no graph category is where the student could not produce a graph.

Interviewer:… So let's go to 1:18. Yep, and watch this approach here. So you see the southbound through are going and southbound left are going. You mentioned that's a protected left turn.

Participant: Yeah.

Interviewer: So southbound continues to go. Now, the northbound gets a green indication, so those through go and they have one left turn. And the southbound through are still going. But then right at the end, there's one more southbound left turn that goes, but he had to wait for a gap. So my question is, why is that? Why were there two different types of left turns during that same cycle for the north and the southbound? Why were there two different types of left turn on that southbound approach? So it started out protected, then it ended up at the end, that vehicle had to wait for a gap to make a left turn.

Participant: Right, well, that's because when the through traffic started going, the protected left turn for both the north and southbound was no longer protected. So you had to wait for the through traffic to get through. And then, once the through traffic was clear, then, because he still had the green indicator, but just not the protected green indicator, he could go through. So that's why this guy could go, and then I think this one went before that one, because there was way more cars going northbound, like you said. This way ___________.

Interviewer: So do you know why that would happen?
Participant: Why?

Interviewer: Why would it switch over like that? So you explained rather well what happened, but can you- -

Participant: Why that would happen?

Interviewer: Yeah, why would that happen?

Participant: Well, let me go back to one, what was it, 1:20?

Figure 4.3 : Example of student repeating the visual sequence of events (VIDRPT)

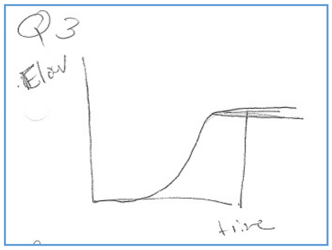
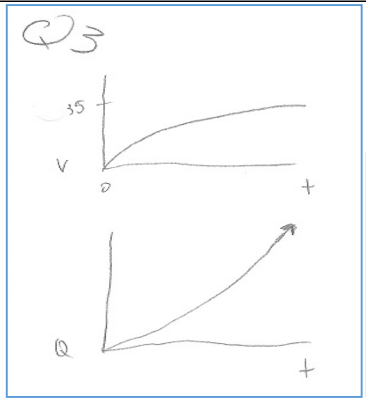
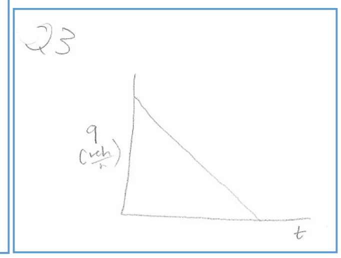
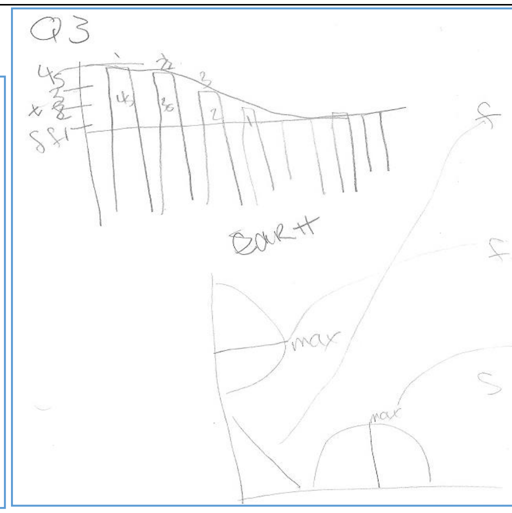
Intuitive graphs	  
Textbook or class graphs	 

Figure 4.4 : Examples of the types of graphs students would produce

Analysis and Results

After following the methods outlined in the previous section the results were assembled in 6 separate schemas that represent the collective student sample. Each schema shows the percentage of the student sample that was coded for a particular category within the schema. There are three schemas that involve signal controller function process, two schemas of traffic behavior process, and one schema of intersection performance. Following each schema is a figure that summarizes the interviewer’s observations while synthesizing the results paired with those observations.

Personal Driving Experience, Guessing, Misconceptions, and Visual Based Information

Table 4.1 shows the frequency of the specific response behaviors. Some students could express the behavior more than once during the interview; consequently there are numbers higher than the sample size. The behaviors are discussed in conjunction with each of the specific schema discussions.

Table 4.1 : Behaviors that students used for support in their responses. Numbers represent the frequency of the respective behavior.

Personal Experience	Admitted Guessing	Miconceptions		Visual Support	
PERSEXP	GUESS	HWLOS	CONFUNCSMRT	VIDRPT	VIDAORD
15	33	7	6	23	40

Signal Controller Processes Schemas

Signal controller processes were separated into three schemas. The first schema, Figure 4.5, is controller safety processes which focus on the specific timing parameters and considerations involved in the change and clearance interval. The second schema, Figure 4.7, presented is signal controller types and processes followed by the schema, Figure 4.9, representing left turn phasing processes. Each schema is followed by a figure that summarizes and pairs the interviewer’s observations with a synthesis of the results.

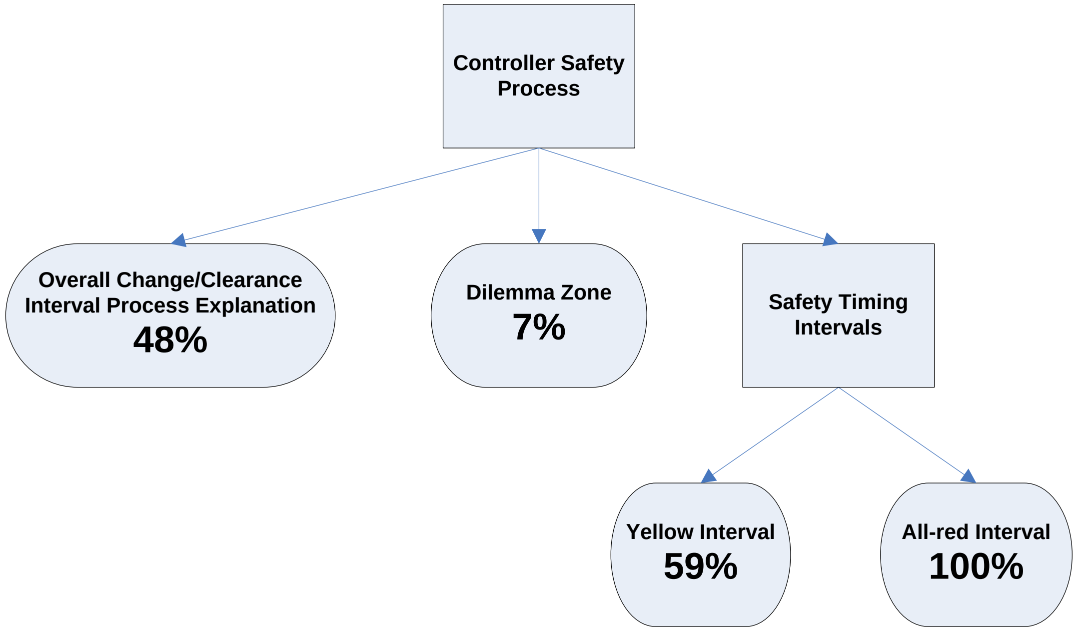


Figure 4.5 : Schema of controller safety process. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Controller Safety (Clearance Interval) Processes
• Less than half (48%) of the students gave an overall description of the change and clearance intervals.
• All students expressed knowledge about the safety impact of all-red interval in comparison to 59% expressing knowledge about the safety impact of yellow interval. This is an important finding because the necessary visual information was available to the student in the video.
• A small portion of students included knowledge about the dilemma zone (7 %). The students who did express dilemma zone knowledge seemed to be repeating textbook or lecture material. It was not clear from observation that students were making the connection with the question or video, suggesting that they had formulated a flawed schema or were simply expressing dilemma zone knowledge as an isolated category that was similar in nature.

Figure 4.6 : Interviewer's observations and synthesis of results for Safety Processes

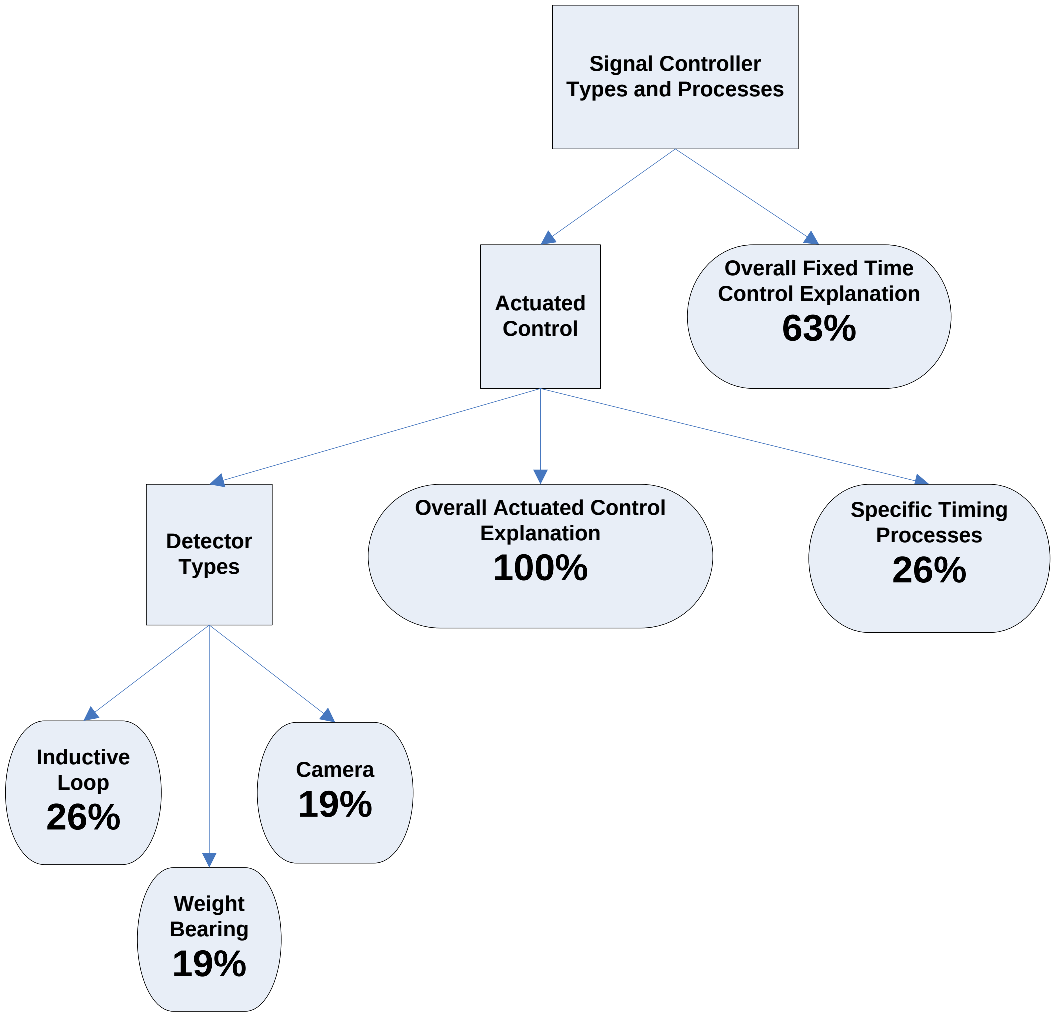


Figure 4.7 : Schema of signal controller types and processes. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Signal Controller Types and Processes
• More students responded with conceptual knowledge about actuated control than fixed time control (100% vs 63% respectively). This result is important because introductory level instruction is primarily focused on fixed time control.
• Of the students that expressed knowledge about actuated control, only a small number (19% - 26%) of students expressed knowledge about detection type or a specific timing process. All of the actuated control knowledge seemed to be coming more from guessing and driving experience rather than from course material. Some students even expressed knowledge of old weight bearing or pressure plate detector technology.
• The highest amount of admitted guessing was found in the actuated process category. There were 21 guesses out of the entire study total of 33. The majority of the guesses were about how the controller functioned. This shows that students were not quite sure how the controller functioned or how the timing processes are managed in the controller. From the coding analysis and the interviewers observations there was probably more guessing than what is reported because in many cases it sounded like a guess but was not coded because the student did not explicitly state they were guessing.
• The highest amount of personal experience used to answer questions was found within the actuated process category. There were 10 instances of personal driving experiences out of the study total of 15. Students most likely applied personal experience in this category because they have a more detailed schema and associated categories from living in a driving culture. “Students will have more experience on the road than they do designing a road” (8). This amount of personal experience is not unexpected considering the students have received limited to no instruction on actuated controllers. This finding does provide evidence that the students believe that their personal experiences are sufficient to answer the questions because personal driving experience schemas are closely related to traffic engineering schemas. Students who apply new engineering knowledge to existing personal driving schemas could struggle to develop proper novice traffic engineering schemas if their existing personal experience schemas are flawed as suggested by (12).

Figure 4.8 : Interviewer’s observations and synthesis of results for Signal Controller Types and Processes.

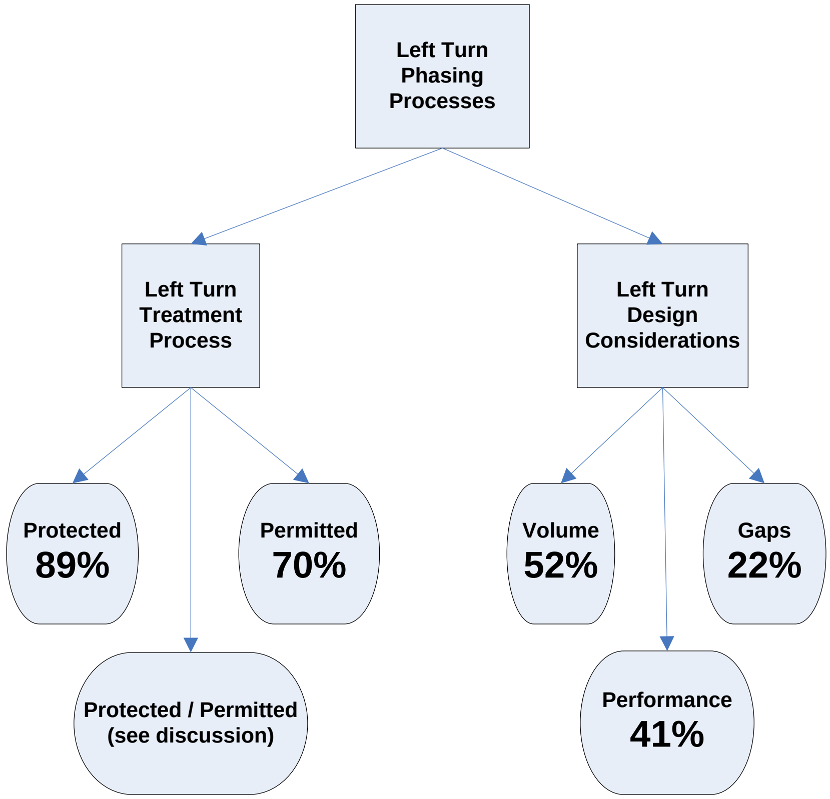


Figure 4.9 : Schema of left turn phasing processes. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Left Turn Phasing Processes
• Students expressed more conceptual knowledge about protected phasing (89%) than they did about permitted phasing (70%).
• Students did not express any knowledge about other left turn treatments such as split phasing or prohibited left turns.
• Similar to controller concept elements, both personal experiences and guessing were again found together with left turn treatment knowledge.
• The number of students responding with conceptual knowledge about protected/permitted phasing category was extremely limited. The protected/permitted concept category showed one of the most peculiar findings where the students would simply repeat the visual sequence (VIDRPT) of the information in the video. Of the total 23 occurrences of VIDRPT, there were 14 found in the protected/permitted category. Students thought the visual sequencing of the video is the answer and could not provide any additional details to answer the questions. Chi (17), reported that novices will focus and use the information presented to them in problems. Cooley (8), found a similar behavior in a pre-semester knowledge survey. This result could indicate a link between visual sequence and personal experience because the left turn treatment concept showed the second highest occurrence (4 out of 15) of personal experience behavior. This behavior, however, may have been a stalling technique to slow the interview down in order to take more time to absorb what they were seeing; students knew very little about protected/permitted phasing, other than navigating or watching it. It could also be an indication that no category exists in their schema from class content or personal experience.
• The design consideration portion of Figure 10 shows the percentages of students who expressed knowledge pertaining to left turn treatment design concepts. The students who did express any knowledge seemed to express more knowledge about left turning volume on the subject approach (52%) than they did about available oncoming gaps (22%) and performance (41%). This result suggests that students are most likely analyzing the subject approach only, rather than the intersection as a whole. It also shows they do not quite understand the balance or interconnectedness between the 3 design concepts and infer that turning volume is the key design principle.

Figure 4.10 : Interviewer’s observations and synthesis of results for Left Turn Treatments

Traffic Behavior Process Schemas

Traffic behavior processes were split into two separate schemas. The first, Figure 4.11, being departure flow where the categories are focused on the departure characteristics of a departing queue of vehicles. The second schema, Figure 4.13, relates to heavy vehicle behavior and signal timing considerations for heavy vehicles. Each schema is followed by a figure that summarizes and pairs the interviewer's observations with a synthesis of the results.

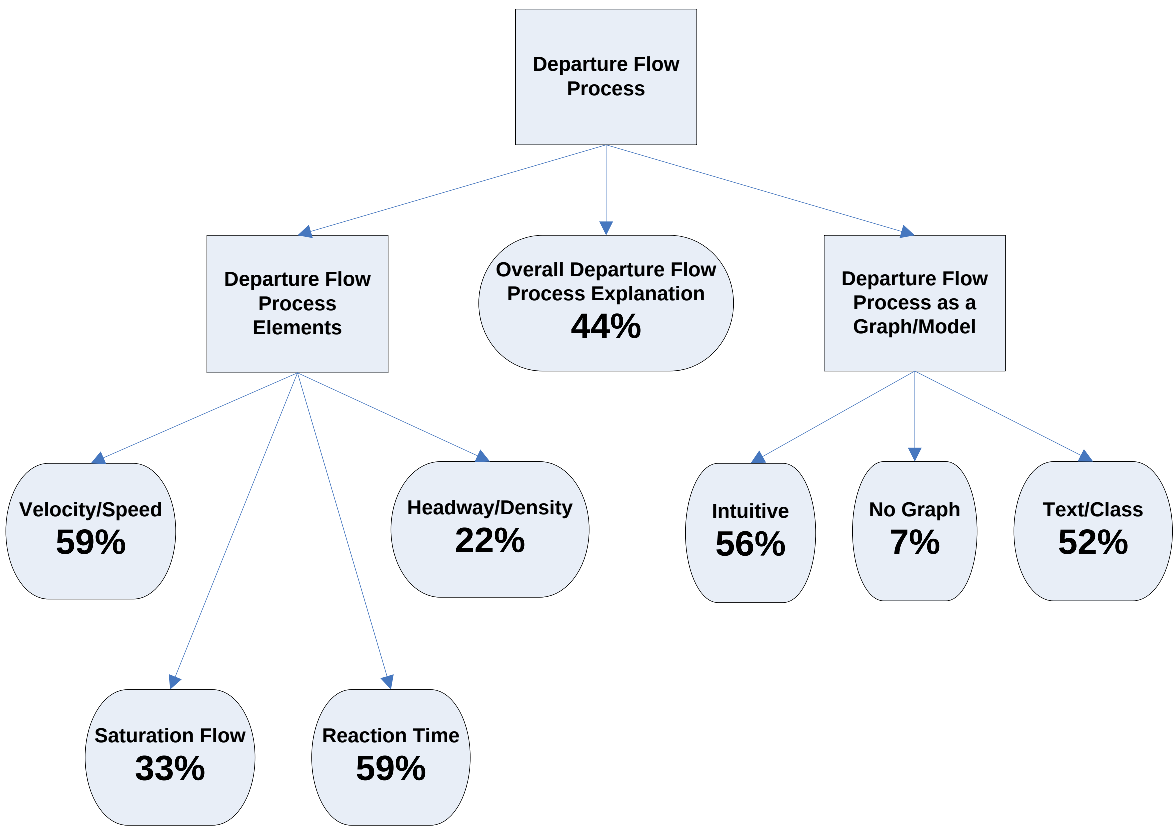


Figure 4.11 : Schema of departure flow processes. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Departure Flow Processes
• A little under half the sample (44%) could explain the entire departure flow process with varied amounts of students describing the specific elements of the process. More students spoke about the velocity portion (59%) of departure flow in comparison to the headway (22%) or saturation flow portion (33%). In some cases it appeared that the students were confusing flow with velocity.
• There were a high amount of responses that addressed reaction time (59%). Though this is an important aspect of signal timing, there is no flow during reaction time.
• For the departure flow category, there was no personal experience, no admitted guessing, and no misconceptions observed. This result could mean that students have developed isolated categories from class material in departure flow. It could also mean that they do not link their personal driving schema to traffic flow. In actual traffic, students participate as a single particle of flow and monitor their own headway rather than analyzing the flow of the entire departing queue.
• There was a high concentration (10 out of 40) of the visual data collection (VIDAORD) observed in the departure flow categories. This shows that students are using visual observations to answer questions rather than knowledge obtained in class.
• There is an approximately even split of the intuitive type graphs produced versus the amount of text/class type of graphs with very few students not producing a graph at all. The amount of intuitive type graphs suggests that students are just as likely to develop their own graph based on observation as they are to use theory that has been presented to them in the introductory class. In some cases the text/class type graphs looked like exact replicas of the text book graphs and did not apply to situation in the video. This possibly indicates that students are memorizing the graph as a picture rather than a conceptual tool embedded in their schema.

Figure 4.12 : Interviewer's observations and synthesis of results for Departure Flow and Graphing

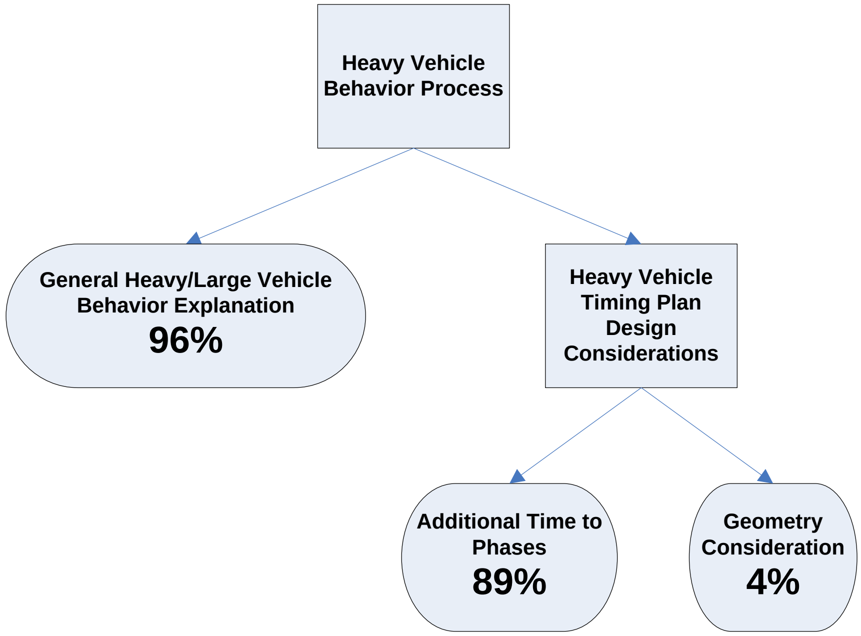


Figure 4.13 : Schema of heavy vehicle behavior processes. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Heavy Vehicle Behavior Process
• The majority of the students (96%) identified with the behavior of the truck. Nearly all students expressed knowledge that trucks were slow and more time should be added to the timing plan. This result showed shallow knowledge about adding time—none of the students expressed any knowledge about what part of the timing plan needed to be adjusted for the truck behavior they described.
• Although there was no personal experience occurrences recorded within the amount of expressed knowledge, it could still be possibly related to personal experience in the driving culture. Most of these students have probably been impeded by a heavy vehicle many times in their driving or riding experiences throughout their life. Introductory classes do not spend a large amount of time on truck behavior (if any).
• The heavy vehicle concept elements also produced misconceptions. Three students confused highway level of service calculations with the question posed to them, referring incorrectly to the heavy vehicle adjustment factor used in highway level of service calculations. This result is evidence of students developing novice schema with categories for different types of analysis that involved heavy vehicles but then making misconceived connections to that schema and intersection analysis. There were also two occurrences of misconceptions where the students thought that the signal controller technology was able to separate large vehicles from passenger vehicles. This example is a potential indication of having an existing flawed schema from the driving culture about the function of the signal controller.

Figure 4.14 : Interviewer's observations and synthesis of results for Heavy Vehicle Operations

Intersection Performance Schemas

The intersection performance schema, Figure 4.15, was related to the students ability to produce a graph or model that represented the intersections performance and if they could assign or identify a measure of effectiveness (MOE). The schema is followed by a figure that summarizes and pairs the interviewer's observations with a synthesis of the results.

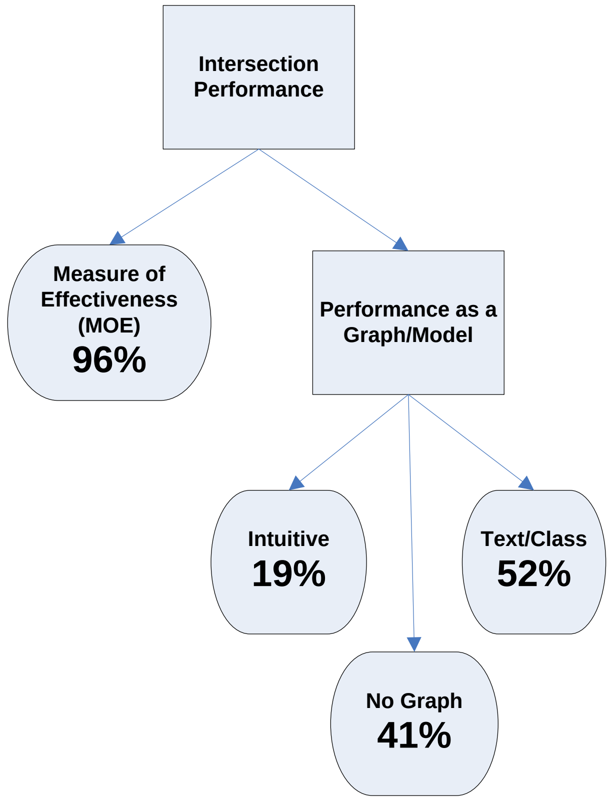


Figure 4.15 : Schema of intersection performance. Percentages represent the amount of responses containing that particular category out of the entire student sample.

Intersection Performance
• There were a high amount (96%) of students responding with some type of relevant performance measure or measure of effectiveness (MOE) knowledge. There were many students who were "taken aback" by the question at first, not knowing what the interviewer meant by performance, but when asked what they thought performance was, most replied with some type of MOE. Clearly, the students had no existing schema for performance at all and some students had to be led into a category of the specific MOE. Typically, students would respond with some form of delay but elements of queue length were present.
• A far lower number of graphs for performance (19) were produced than graphs for departure flow (29). Eleven students said they could not produce a performance graph. This result is a significant finding because many of the students could have used the graph they produced for departure flow as a performance graph. For example, some students chose to produce variations of the d/d/1 queuing model. This graph could be used to show both departure flow and performance in the form of delay or queue length. This result shows that students' categories of intersection performance and queuing theory are not strongly connected.
• More students produced text/class type graphs (52%) than producing intuitive type graphs (19%), unlike the graphs for the departure flow concept, where there were relatively equal amounts of both. Viewing this in conjunction with lack of graphs for performance shows that students have trouble making connections between traffic flow theory, performance, and field observations.
• There were 4 instances of misconception where students, again, responded with concepts regarding highway level of service calculations and techniques. This result suggests that students have not separated highway analysis from intersection analysis, again making a loose connection to a performance calculation for highways because it's some kind of performance

Figure 4.16 : Interviewer's observations and synthesis of results for performance

Summary, Conclusions, Implications, Recommendations, and Future Research

The purpose of this research was to develop pertinent hypotheses, theoretical propositions, relevant questions, and research directions for conclusions. This work was done in the area of signalized intersection operations education to focus future research that aids in the development of better curricula and instruction for transportation engineers. This study took an exploratory case study approach by collecting and analyzing qualitative data from a relatively small sample of engineering students from two universities in the Inland Northwest. The analysis documented the student knowledge structure of signalized intersection concepts after completing the introductory transportation engineering course. The knowledge structure was presented as schemas of ontological categories. These conclusions are presented in this section.

Conclusion 1

Student ontological categorization of signalized intersection concepts appears to be limited in depth and provides limited amount of details. The categorization is also appears to be disorganized with evidence of misconceptions and disconnected between traffic theory and the application of that theory to actual traffic processes.

Supporting data

- Most of the percentages displayed in the schemas seem low. These were collective schemas and, therefore, some students did not have any category for a particular concept at all.
- When asked questions where they could have used classroom knowledge they typically did not. Students typically reverted to personal driving experience or derived answers from observable content of the video. Over 63 combined instances of the students simply repeating the visual content or using data collected from the video to answer questions were observed and analyzed. This result suggests that proper ontological categories are not established well enough to support reasoning or are non-existent.
- There were 33 occurrences of admitted guessing sometimes supported with personal experience. This guessing behavior would also suggest that the knowledge structures developed in class are not strong enough to support reasoning about signalized intersection concepts or simply that these structures have not been established.
- There were 13 documented instances of clear misconceptions. Students confused highway level of service calculations with signalized intersection performance. Also, instances of students misconceiving the function of the controller and thinking it’s more advanced than it is.

- Students struggled to connect traffic theory and actual traffic process. In several instances students were unable to make clear connections between class content to the traffic processes in the video. For example, a student could provide a graph of traffic flow but could not provide one for performance although the student could have used the same graph for both. Some of these graphs were developed on the spot using only their intuition and data from the video. Some of these graphs were almost 1:1 versions out of the text and not from a connection to the traffic process taking place in the video.

Conclusion 2

Student ontological structure of signalized intersection concepts is closely related to personal driving and riding experiences. The creation of ontological categories based on personal driving and riding experiences seemed to be stronger than the ontological categorization or knowledge structure of engineering concepts for signalized intersections. Evidence of such trends has been identified in previous research (1) (8).

Supporting data

- Interviewer observations indicated that students did not seem to use much classroom or engineering type knowledge for support.
- To reinforce the interviewers observations; there were 15 documented occurrences of personal driving experience used as support in students responses. These documented personal experiences were paired mostly within explanations of actuated controller function and left turn phasing descriptions. Both of these concepts also yielded a high percentage of the sample using these conceptual categories.
- Three particular categories yielded very high percentages of conceptual content compared to others. They were heavy vehicle behavior, timing plan design considerations for heavy vehicles, and the all-red safety interval. All three concepts were approximately 90 % or higher in the respective schemas. The connection to personal experience here is that there is very little time if any spent on these concepts in the introductory class with the exception of the all-red interval but in the scope of

a semester it’s still a small amount of time. Heavy vehicle interaction in the driving culture would likely influence the conceptual understanding of these concepts.

Implications of these Conclusions on Learning

It must be stated that introductory transportation engineering students are not typically questioned in the face of field observation and the interviews were most likely highly out of context for them. They are typically in the habit of assigning the correct variables to equations when asked to calculate quantities. It should also be noted that these students did not fail their introductory transportation engineering course and were on track to graduate from their program. With that said there are some implications of the way their knowledge is categorized.

Implications on learning are that their current categorization is potentially harmful or was harmful to conceptual change. Literature on the subject of conceptual change states that when new knowledge is presented to students they will compare it to existing categories or begin to develop new categories (12). Based on the presentation of this new knowledge the student either accepts or rejects the new knowledge (2) (12). Categories of driving experiences are very similar to categories of transportation engineering and may be interfering with the proper development of an engineering knowledge structure. There may be cases where engineering content is simply being rejected because it does not match well established and similar driving experience. There may be cases where the new information is accepted but it’s only enhancing a driving experience categorization. If their existing driver schema is flawed and there is not enough opportunity to resolve conflicts then conceptual change will not occur, there will be misconceptions, confusion, and relationships not developed.

The more opportunity a student has to compare and contrast new knowledge to existing schemas will ensure the categories become better established and organized (1) (2) (12). If students do not have enough opportunity to compare, contrast, and resolve conflicts then conceptual change will be difficult. In the case of the introductory class, there is a very broad and brief sampling of the many topics involved in transportation engineering. A limited amount of time is spent on each topic. In addition these topics do not build upon themselves. For example geometric design concepts offer no support structure for traffic flow theory, signal timing, or planning concepts. There may not be enough time spent on any one topic during a semester for a student to effectively restructure or develop categories from the driver to the engineer.

Research Directions and Questions

- The methodology presented in this study should be repeated on a larger sample that encompasses a larger geographical area and more universities to see if the same findings can be repeated.
- Analyze the data from this study again but separate proper engineering vocabulary from accuracy of the responses to see if there is a difference.
- What are the expectations of educators who teach the introductory course? Are these findings acceptable?
- There is no other study like this to compare to so are these findings good or bad?
- What is the appropriate amount of time and pedagogy required for a student to restructure and reorganize categories from driver to engineer.
- How dominant is driving experience? How much does their driving experience interfere with reorganizing existing ontological categories or developing new ones?
- Can their driving experiences be efficiently used as a foundation for education?

CHAPTER 5: STUDENTS' KNOWLEDGE PROFILES

Introduction

The objective of this analysis of the second case study was to provide further evidence of a personal driver or non-engineer type knowledge structure of signalized intersection concepts amongst undergraduate civil engineering students. This analysis used data and results from the analysis of the second case study explained in Chapter 4 that resulted in several conclusions and research directions but the ones of interest for the study presented in this chapter are as follows:

- Conclusion 2 from Chapter 4
    - Student ontological structure of signalized intersection concepts is closely related to personal driving and riding experiences. The creation of ontological categories based on personal driving and riding experiences seemed to be stronger than the ontological categorization or knowledge structure of engineering concepts for signalized intersections. Evidence of personal driving experience has been identified in previous research (1) (8).
- Research direction from Chapter 4
    - Analyze the data from this study again but separate proper engineering vocabulary from accuracy of the responses to see if there is a difference.

The conclusions were developed by analyzing responses from interviews where 27 undergraduate students who recently completed their introductory transportation engineering course. The students were asked questions related to actuated traffic signal operations while watching a video of an actuated intersection. These responses were analyzed within the framework of ontological categorization of knowledge which involves looking into the hierarchal structure of knowledge and the implications it has on conceptual change. A concept is a piece or subset (schema) of this hierarchal knowledge structure. Conceptual change is the structuring and restructuring of hierarchal categories of knowledge. Among the results of the analysis, 6 collective schemas were developed, and 15 documented occurrences of personal driving experiences were found in the student responses. Using the research direction listed above will lead to further evidence to support the listed hypothesis and provide a measure that is more generalizable to entire 27 student sample.

This study makes a comparison between the conceptual accuracy levels of the student responses versus the engineering vocabulary levels used by the students. A knowledge profile is a good tool for making comparisons like this (19). A knowledge profile, simply stated, is a graph that represents a score or level on the y-axis and a particular concept or schema of knowledge on the x-axis. These knowledge profiles presented in this study show side-by-side comparison of accuracy and vocabulary levels for the same schemas of knowledge.

Personal driving experience have been found in student responses in introductory transportation engineering course as well as design level course research (1) (8). The work in Chapter 4 found evidence to suggest that students were using personal driver-like categories that seemed to exist at a higher priority than transportation engineering-like categories. Observations were made that although students were using driver-like vocabulary; they seemed to have a more conceptually accurate categorization of some processes.

For example, a student might be accustomed to calling vehicles waiting to be served a "line." In learning transportation engineering vocabulary, this student would have to change a new vocabulary called queuing. However in this case, the student is not wrong; he is just using the incorrect transportation engineering vocabulary. The hypothesis for this study is that students can be more conceptually accurate than their vocabulary suggests.
If the hypothesis is correct, it would provide further evidence that students possess much stronger driver-like categories than they do transportation engineering categories. Using other vocabulary for a particular concept implies that there is a different categorization for that concept.

Research in the field of conceptual change concludes that concepts and schema that are well established are difficult to rearrange, making conceptual change more difficult to achieve

(12). Furthermore, these results provide support for further research to understand how important these pre-existing, personal, driver-like concepts are to learning and help to adjust curricula.

Background

Knowledge profile

A knowledge profile is defined by plotting scores on a graph along a dimension and a set of parameters (19). Figure 5.1 shows a general example of a knowledge profile with a set of parameters for a content dimension on the X-axis. The Y-axis is a score or assessment level. The X-axis parameters and dimensions are derived from the study of hierarchal structures of knowledge, or ontology (19). For example, vehicle departure flow could be considered a concept dimension or schema and its parameters or concepts could be velocity, headway, reaction time, and saturation flow.

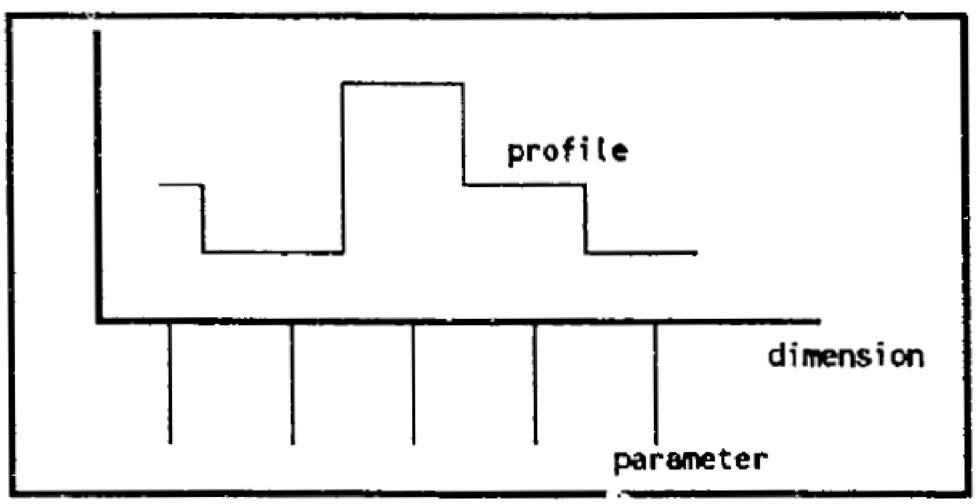


Figure 5.1 : Example of knowledge profile from Wagemans (19)

Study Methodology, Data Reduction, and Validation

The methodology for this chapter assigned conceptual accuracy levels and engineering vocabulary levels to each category in the predetermined schemas developed in Chapter 4. There were 33 novice level categories that fell under three major concept areas: 1) three schemas of signal controller function processes, 2) two schemas of traffic behavior processes, and 3) one schema of signalized intersection performance. Once these levels were determined they were plotted on a knowledge profile graph to make comparisons. This section will discuss data reduction and data validation procedure.

Data Reduction

Conceptual accuracy and engineering vocabulary were assessed independently from each other. Figure 5.2 provides definitions of each accuracy and vocabulary level used in this study. For each category within the established schema, a separate conceptual accuracy level and a separate engineering vocabulary level were assigned to each student response (if the student expressed knowledge in the respective category). Level 1 is defined as the expert level or the level at which these concepts are taught in the introductory transportation engineering course.

Therefore, in this case, someone with an advanced degree in the subject who has taught or regularly teaches these concepts would be considered the expert. The accuracy levels are primarily focused on the amount and type of details collected in a student response. The engineering vocabulary levels are focused on specific transportation engineering terms that would be appropriate for the explanation. For example a student can describe the process of an actuated controller in personal non-transportation engineering terms (Level 4) and be highly accurate in the details of the process (Level 2).

An example of how the accuracy and vocabulary levels were assigned is presented using the quotation in Figure 3.3. In the first portion of the response in Figure 3.3, the student talks about a “sensor” or “some sort of device that detects”. The student is then asked to provide more information about sensing. Accuracy and vocabulary codes of ACC2 and VOC4 were assigned. The ACC2 code was assigned because the student is supplying conceptual details about the presence or lack of presence of demand at the intersection approaches, which leads the students to believe that the intersection is actuated.

Code	Definition
Accuracy Level 1 (ACC1)	Responses contain nearly (100%) conceptual accuracy in relation to the question. The response contains an expert level of well-defined details to support the response.
Accuracy Level 2 (ACC2)	Responses can contain slight misconceptions in conceptual accuracy but it can be understood that the response addresses the question. Additionally, the response is missing a few key details for the explanation of the concept but is conceptually accurate.
Accuracy Level 3 (ACC3)	Responses are conceptually accurate but have limited details or the concept may not necessarily need much detail. The response contains sufficient amount of vague details to support their answer.
Accuracy Level 4 (ACC4)	Responses can contain several misconceptions, several vague or missing details, or are partially related to the questioned posed. Contains driver type details
Accuracy Level 5 (ACC5)	Responses are totally misconceived, hardly any details, or not related to the question. Contains driver type details
Vocabulary Level 1 (VOC 1)	Responses contain nearly 100% accurate and applicable vocabulary. Students sound like the expert level vocabulary when explaining concept
Vocabulary Level 2 (VOC 2)	Responses contain several vocabulary elements specific to the overarching concept but other details may have a personal/driver/non-engineering vocabulary
Vocabulary Level 3 (VOC 3)	Responses contains one vocabulary element specific to the target concept, doesn't necessarily need specific vocabulary, or have vocabulary that an expert might use but its rather "loose" explanatory vocabulary.
Vocabulary Level 4 (VOC 4)	Responses contain instances where the target concept vocabulary is not used but may include some acceptable vocabulary elements. Also acceptable vocabulary used may not apply to the concept and the response sounds very personal/driver/non-engineering
Vocabulary Level 5 (VOC 5)	Responses contain hardly any relevant transportation vocabulary and is mostly personal/driver/non-engineering sounding. It's clear that the student does not know the proper vocabulary and terminology.

Figure 5.2 : Definitions of accuracy and vocabulary levels

Furthermore, the student supplies details from personal experience as further details to support reasoning when asked to explain how “sensing” may work. This was considered a rather high conceptual accuracy but lacked some details, like detection type or focused detailed timing process interactions so it was not worthy of an ACC1. A VOC4 code was assigned because the student never called it an actuated intersection but there was the use of the word “queue”, which is an acceptable transportation engineering term.

Referring back to the second part of the response in Figure 3.3, where the student is asked to expand on “timer”. The response was given codes of ACC1 and VOC 4. ACC1 was assigned because the student provides accurate details to answer the question presented. The vocabulary still does not provide the proper target concept terminology of a fixed or pre-timed intersection but has a few other acceptable terms like “protected left”.

Once the accuracy and vocabulary levels were developed, the data were reviewed again and coded following the procedure in Chapter 4. Data management was facilitated with the aid of professional qualitative data analysis software (Atlas TI). The benefit of using this type of software is that it manages specific quotations in the transcriptions. The software also keeps accurate counts of the codes and provides co-occurrence of codes, for example, how many ACC2 codes were assigned to the concept of saturation flow. After the second iteration through the data, the accuracy and vocabulary codes were summed, and tabulated for each student and for the entire sample per developed schema.

Data Validation

There were some validity concerns while assigning the accuracy and vocabulary codes. The first issue is that only one researcher (Grad 1) reduced the entire data set. This could lead to some possible bias in the results because of stopping and starting the data reduction over the length of time it took to complete the analysis. Second source of bias was potentially introduced with the “fuzzy” boundaries of the specific accuracy and vocabulary level definitions. Responses from the sample of students varied, and it was difficult at times to pin-point and assign specific accuracy or vocabulary level.

To keep a check on bias, three university faculty experts in the field of transportation engineering were asked to code a sample of student responses in the same method that is described above. The experts were all licensed professional engineers who have a doctorate degree in civil engineering with focus in transportation engineering and have taught the transportation engineering introductory course several times. To gain familiarity and perspective with the data reduction process, the experts participated in the same interview that was given to the students and were asked to listen to their responses first before coding two student interviews following the process described above.

In addition to the faculty experts coding a sample of the data, an additional graduate student (Grad 2) from an outside university/program was tasked to code a sample as well. Grad 1 and the faculty experts were from the same university/program and Grad 2 provides some additional validity support from an outside perspective. Grad 2 was given two random interviews from the same pool of interviews as the faculty experts were given.

After the faculty experts and Grad 2 coded their respective interviews, their answers were compared to the reduced data, by Grad 1, for the same students. By comparison; if the accuracy and vocabulary levels were similar, then it can be said the process is “valid” as are the results. If they are different, then validity depends on how the levels vary. If all faculty experts uniformly assign better/worse accuracy and better/worse vocabulary, then the same trends will most likely be valid because it’s merely a shift by some factor from the reduced data results.

Study Findings

The findings section begins with the results of the data validation experiment followed by the findings from the entire student sample.

Data Validation Results: Conceptual Accuracy

The accuracy levels assigned by Grad 1, the three faculty experts, and their combined average are distributed and presented in Figure 5.3. The faculty experts tended to give the students worse scores than the comparison sample completed by Grad 1. The faculty experts produced an average accuracy level of 3.5 with a standard deviation of 0.9 and the comparison sample had 2.7 and 1.1 respectively. There is a noticeable spike in the level 4 results because one of the experts assessed one student with all but one level 4. A statistical t-test, at an alpha level of 0.05, was performed on the mean values and the result confirmed that the means were not statistically equal. With no known acceptance level for the difference between means for this type of data, it is difficult to say what exactly can be inferred by the statistical test.

Table 5.1 shows a more focused, or microscopic, comparison of the validation and shows the results for each validation participant and respective student. By examining the results in Table 5.1, it can be seen that Expert 1and Grad 1 assessed ST4 WSU as having a higher accuracy level than ST6 UI; there was a similar trend with Expert 3 and the respective students. This indicates that the same assessment of the student is taking place but suggests that there is a shift in the understanding and application of the accuracy assessment criteria in Table 1. The data reduction expert may have been somewhat more lenient in the amount and type of details that were accepted for the accuracy codes.

Examining Table 5.1 and considering Grad 2's assessment there are some inconsistencies. For example the comparison of ST4 WSU and ST3 UI for faculty experts and Grad 1 show that ST4 WSU scores higher than ST3 UI but Grad 2 reports an opposite trend. Also, examining the scores for ST3 UI the difference between Grad 2 and Expert 3 is very large. The source of this inconsistency is unknown. Examining the scores for ST4 WSU there is consistent scoring and all three assessments agree that ST4 WSU is above level 3.

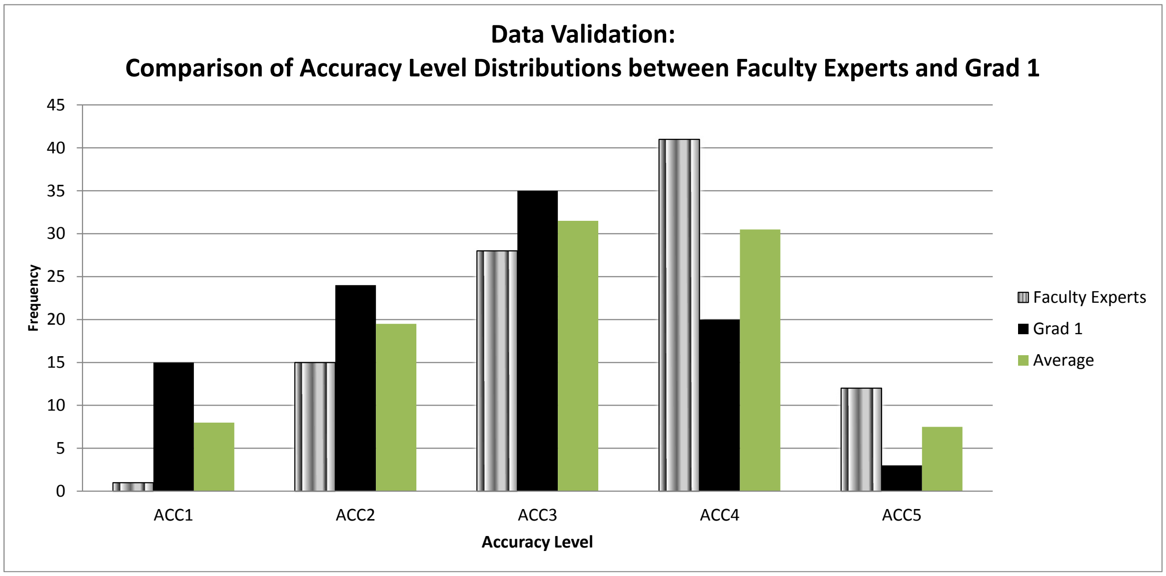


Figure 5.3 : Validation comparison distribution for accuracy level

Table 5.1 : Accuracy level results for all faculty experts, Grad 1, and Grad 2. The numbers in parenthesis are the averages for just ST4 WSU and ST3 UI to compare with Grad 2.

Accuracy Level Validation Results		Faculty Experts		Grad 1		Grad2	
		Average Accuracy Level	Standard Deviation	Average Accuracy Level	Standard Deviation	Average Accuracy Level	Standard Deviation
Expert 1	ST6 UI	4.0	0.9	2.8	0.7	---------------	---------------
	ST4 WSU	2.5	0.7	1.8	1.1	2.6	0.5
Expert 2	ST11 WSU	3.3	0.7	3.2	1.1	---------------	---------------
	ST15 WSU	3.9	0.3	3.2	0.8	---------------	---------------
Expert 3	ST7 WSU	4.0	0.7	3.1	1.2	---------------	---------------
	ST3 UI	3.8	0.9	2.5	0.9	1.6	0.8
	Total	3.5 (3.1)	0.9 (1.0)	2.7 (2.2)	1.1 (1.0)	2.1	0.8

Due to their teaching experience, the faculty experts have much more familiarity in assessing students for this type of content, so their natural process of assessment could have been influencing the lower accuracy scores. The faculty experts' level of expected details in combination with vocabulary may have also interfered with their assessment. The attempt here was to assess vocabulary and conceptual accuracy independently, but this was at times very difficult. A refinement of the accuracy criteria in Figure 5.2 may reduce this discrepancy in the future.

Figure 5.4 shows the overall conceptual accuracy distribution for the entire sample determined by Grad 1. The entire sample contained 434 instances of expressed knowledge to score identified by Grad 1 during the data reduction. An average accuracy level of 3.2 with a standard deviation 1.3 was determined. This suggests that on average, the sample has some basic conceptual understanding of the concept but can only produce limited vague details to support their understanding. The standard deviation is approximately one level above or below level 3 which indicates that some students have fair conceptual accuracy with good detail, or they have misconceptions with non-focused driver-like details. Taking the faculty expert validation results into account, the findings could be shifted slightly further to the right than shown in Figure 5.4. The best estimate of accuracy is most likely the combined average shown in Figure 5.3 in which an average of 3.1 was calculated. This still suggests that students perform slightly below the level 3 criteria.

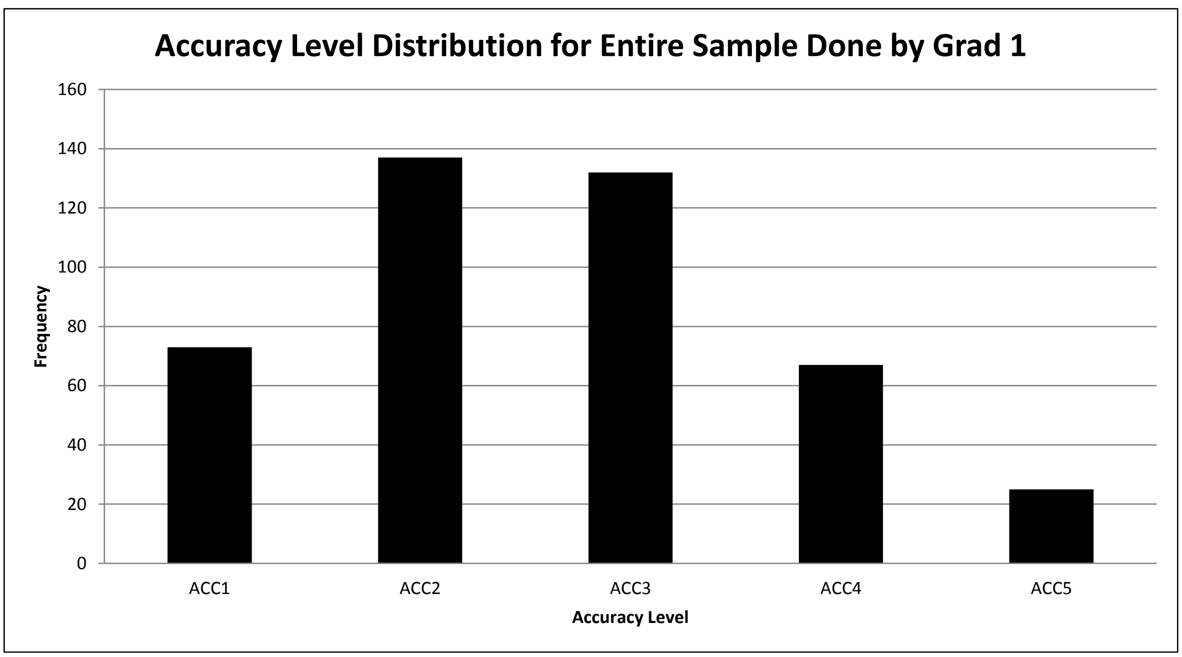


Figure 5.4 : Overall accuracy distribution from initial data reduction for the entire sample. Vocabulary

Data Validation Results: Engineering Vocabulary

Similar to accuracy, the vocabulary levels assigned by Grad 1, the three faculty experts, and their combined average are distributed and presented in Figure 5.5. In this case the data do not appear to be normally distributed and are skewed to the right. Although skewed, the averages and standard deviations between experts and comparison samples are close. The faculty experts had an average of 3.7 and standard deviation of 1.0, and the data reduction expert had 3.9 and 1.1 respectively. Since data are not normally distributed, a t-test was not performed on the mean values. There is also a discrepancy between the level 4 and 5 results; they are seemingly opposite. This was because Expert 2 recorded all level four on one of the students and caused the spike in level fours.

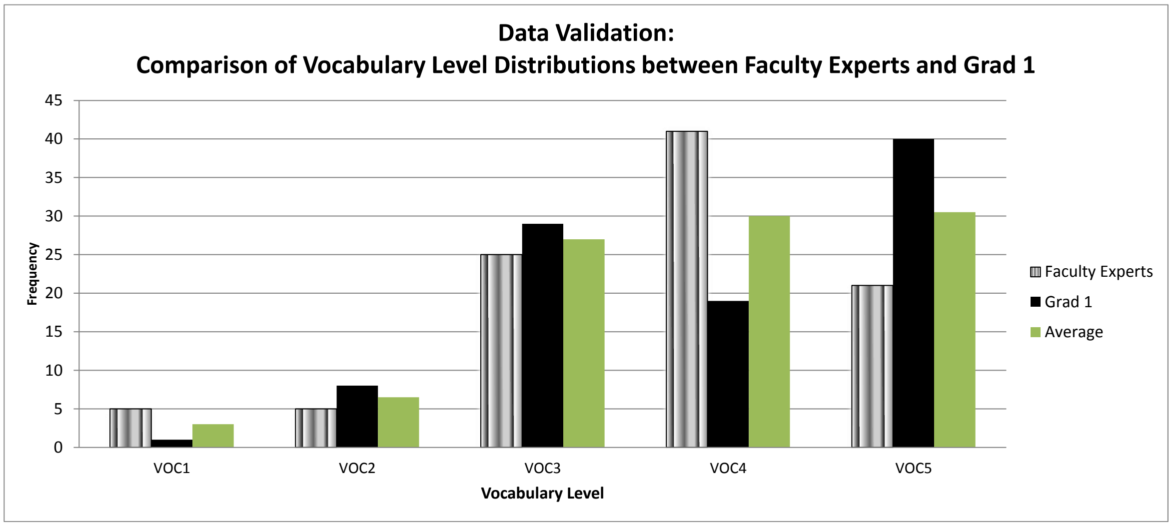


Figure 5.5 : Validation comparison distribution for vocabulary level

Examining Table 5.2, a similar trend with the accuracy can be seen. Again, Expert 1 and Grad 1 assessed ST4 WSU as having a higher vocabulary level than ST6 UI and there was a similar trend with the other experts and their respective students. Additionally, the difference in averages between the faculty experts and data reduction expert is much smaller in comparison to the accuracy results. This suggests that the vocabulary criteria in **Error! eference source not found.** are more clear and consistent.

Considering Grad 2's assessment in Table 5.2 there is another inconsistency and it is with ST3 UI again. Expert 3 and Grad 1 assess the student's vocabulary very close and Grad 2 is approximately a full level difference. This might be a shift as discussed earlier but when looking at the comparison ST4 WSU to ST3 UI there is an opposite trend to the faculty experts and Grad 1.

Table 5.2 : Vocabulary level validation results for all faculty experts, Grad 1, and Grad 2. The numbers in parenthesis are the averages for just ST4 WSU and ST3 UI to compare with Grad 2.

Vocabulary Level Validation Results		Faculty Experts		Grad 1		Grad 2	
		Average Vocabulary Level	Standard Deviation	Average Vocabulary Level	Standard Deviation	Average Vocabulary Level	Standard Deviation
Expert 1	ST6 UI	3.8	1.3	3.7	1.0	----------------	----------------
	ST4 WSU	3.1	1.3	3.2	1.3	3.1	1.0
Expert 2	ST11 WSU	3.5	0.7	4.0	1.1	----------------	----------------
	ST15 WSU	4.0	0.0	4.4	0.8	----------------	----------------
Expert 3	ST7 WSU	4.6	0.5	4.4	1.1	----------------	----------------
	ST3 UI	3.8	0.8	3.9	0.8	2.6	0.6
	Total	3.7 (3.4)	1.0 (1.1)	3.9 (3.6)	1.1 (1.1)	2.9	0.9

Figure 5.6 shows the overall vocabulary distribution for the entire student sample determined by Grad 1. An average vocabulary level of 4.0 was calculated with a standard deviation of 1.0. This suggests that on average students use non-transportation engineering vocabulary when explaining observations of traffic signal operations in field conditions. The results show that majority of the students do not use the target concept vocabulary in their answers. The standard deviation of one level and the skewed distribution shows that for some concepts the students at least know the target concept vocabulary appropriately, but other concepts sound very driver-like.

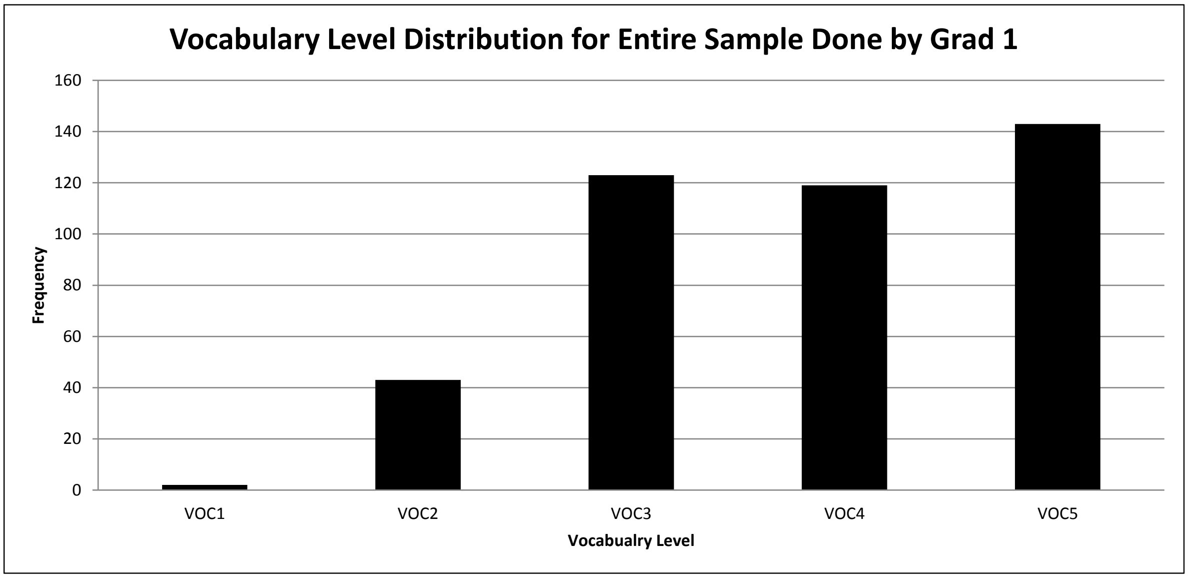


Figure 5.6 : Overall vocabulary knowledge profile for all categories

Accuracy and Vocabulary Side-by-Side

When considering some of the shifts between validation participants in both accuracy and vocabulary levels, the inconsistencies reported by Grad 2, a different type of presentation might show some consistency in the validation. Here the analysis will focus on the individual assessments rather than between or cross the validation participants. Table 5.3 shows the accuracy and vocabulary scores side-by-side and then the answers to two questions. The first question is whether the vocabulary score is lower or higher than the accuracy level. The 3rd column in Table 5.3 shows the results to the question. Answering this question for each student independently will remove any misunderstandings the validation participants had with the coding process. It shows a more generalized answer to whether the validation participant assessed the vocabulary level lower or higher than accuracy. The overwhelming answer to this question was lower with all but one assessment showing a lower vocabulary score. Before moving on there had to be a significance level set to say how much lower.

A significance level of 0.5 of level. This level was chosen for the potential “gray area” or when a validation participant may have been “on the fence” about choosing a specific accuracy or vocabulary level. Column 4 in Table 5.3 shows the mathematical difference between accuracy and vocabulary scores and column 5 shows the answer to whether the column 4 is greater than 0.5. The overwhelming answer to this question was yes with only 4 no's. Examining the last row of Table 5.3 where the average is taken and the same questions presented to the average confirms that the students assessed in the validation had a vocabulary score that was at least a half level lower than there accuracy score.

Table 5.3 : Comparison of accuracy and vocabulary levels with columns showing the differences.

Accuracy Level Compared to Vocabulary Level		Average Accuracy Level	Average Vocabulary Level	Is the Vocabulary Lower or Higher than Accuracy?	Mathematical Difference	Is the Difference Greater than 0.5?
Faculty Experts	**ST6 UI**	4.0	3.8	Higher	-0.3	NO
	ST4 WSU	2.5	3.1	Lower	0.6	YES
	ST11 WSU	3.3	3.5	Lower	0.1	NO
	ST15 WSU	3.9	4.0	Lower	0.1	NO
	ST7 WSU	4.0	4.6	Lower	0.6	YES
	ST3 UI	3.8	3.8	Lower	0.1	NO
Grad1	**ST6 UI**	2.8	3.7	Lower	0.9	YES
	ST4 WSU	1.8	3.2	Lower	1.4	YES
	ST11 WSU	3.2	4.0	Lower	0.8	YES
	ST15 WSU	3.2	4.4	Lower	1.2	YES
	ST7 WSU	3.1	4.4	Lower	1.3	YES
	ST3 UI	2.5	3.9	Lower	1.4	YES
Grad2	**ST4 WSU**	2.6	3.1	Lower	0.6	YES
	ST3 UI	1.6	2.6	Lower	1.0	YES
Total	All Assessments	3.0	3.7	Lower	0.7	YES

Knowledge Profiles of Schemas by Major Content Dimension and Parameters

Presented now are the knowledge profiles for the six predetermined schemas developed in Chapter 4. Each knowledge profile is an aggregated and averaged representation of each schema within the three major concept areas. For example the schema of departure flow process shown in Figure 4.11 has eight subcategories. The accuracy and vocabulary scores were averaged for seven (the no graph category not included) categories and plotted in the knowledge profile in Figure 5.8. The order of presentation is first the three schemas of signal controller function processes, second the two schemas of traffic behavior processes, and third the schema of intersection performance. Additional findings and observations from the data reduction follow each knowledge profile in a bulleted list. The knowledge profiles are built from the accuracy and vocabulary scores assigned during the data reduction prior to the validation experiment.

Signal Controller Function Processes Knowledge Profile

Figure 5.7 shows the knowledge profile for the three concept schemas of signal controller function processes developed in Chapter 4. There are six categories averaged in the Signal Controller Types and Processes schema, six categories in Left Turn Phasing Processes, and four categories in the Safety Process.

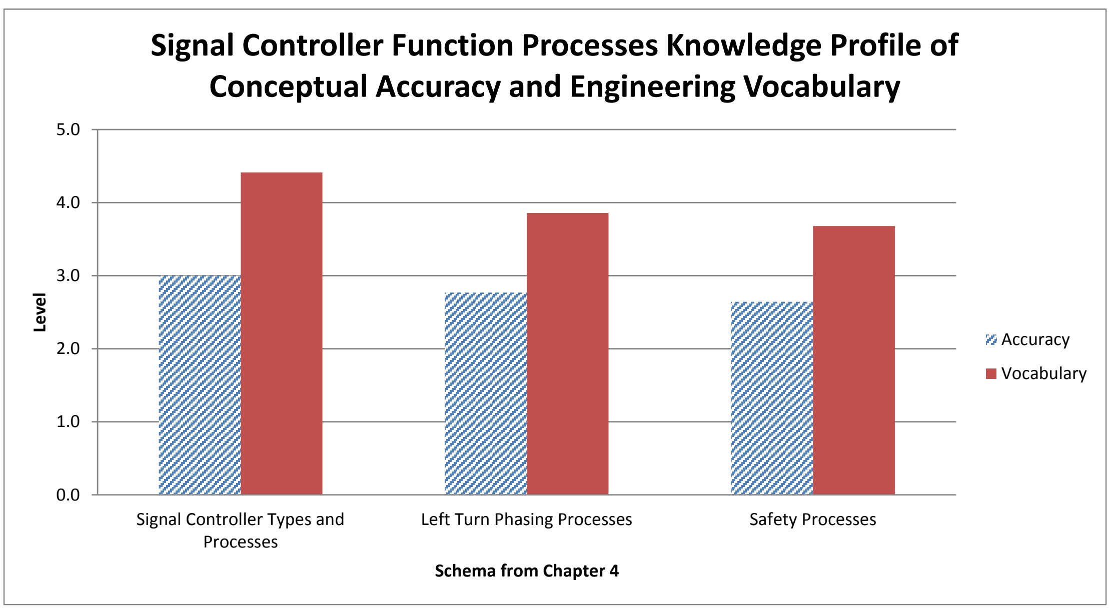


Figure 5.7 : Controller function processes knowledge profile.

- Safety Processes
    - Conceptual accuracy was relatively high in comparison to other categories and vocabulary was also higher. This is not surprising because safety interval vocabulary is common in the driving culture well before they entered a transportation engineering curricula.
- Signal Controller Types and Processes
    - Although there was a high amount of guessing and personal experience associated with this concept, it appears that the student's guesses were conceptually correct with the majority of accuracy scores to the high side of the distribution.
    - In contrast, it shows that students did not retain or use the vocabulary associated with the content. Only 4 students used the term actuated control and only 1 student used fixed time control.
- Left Turn Phasing Processes
    - The protected left turn phasing showed the best vocabulary out of any concept element in the study with an average score comparable to their accuracy score.
    - Left turn conceptual accuracy scores show that students have a good understanding of some left turning concepts, however it seems to be related to their intuition and experiences and not from knowledge obtained from class.
    - Nearly all students expressed knowledge about a left turn treatment at an accuracy level of 3. Of those students only half expressed knowledge about how left turn treatments are chosen or designed. The accuracy of those who did was closer to level 2. More students understood the subject approach volume consideration of design than they did available gaps or a performance measure.

Traffic Behavior Processes Knowledge Profile

Figure 5.8 shows the knowledge profile for the two concept schemas of traffic behavior processes developed in Chapter 4. There are seven categories averaged in the Departure Flow Process schema and three categories in the Heavy Vehicle Behavior Process schema.

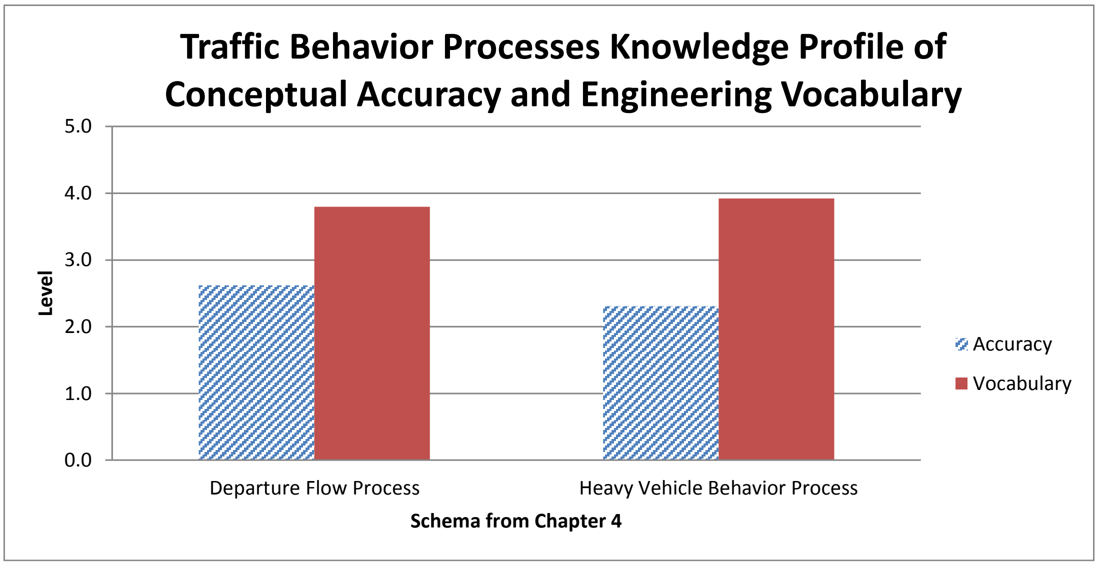


Figure 5.8 : Traffic behavior processes knowledge profile.

- Departure Flow Process
    - Departure flow and graphing concept elements followed a reoccurring trend where conceptual accuracy is better than vocabulary but with smaller standard deviations than other concept elements.
    - When students were referring to saturation flow, only one student used the proper vocabulary.
    - There is an approximately even split of graphs where students would use their intuition to produce a graph versus the amount of textbook/class type of graphs with very few students not producing a graph at all. The accuracy associated with students identifying the portion of their graph that represents departure flow was high. Approximately half the students who produced a graph could correctly identify elements of the graph.

- Heavy Vehicle Behavior Process
    - The heavy vehicle concept element saw some of the highest accuracy. Nonetheless, the students were still limited in the vocabulary elements.

Intersection Performance

Figure 5.9 shows the knowledge profile for the concept schema of intersection performance developed in Chapter 4. There are three categories averaged in the Intersection Performance schema (the No Graph category is not included in the average).

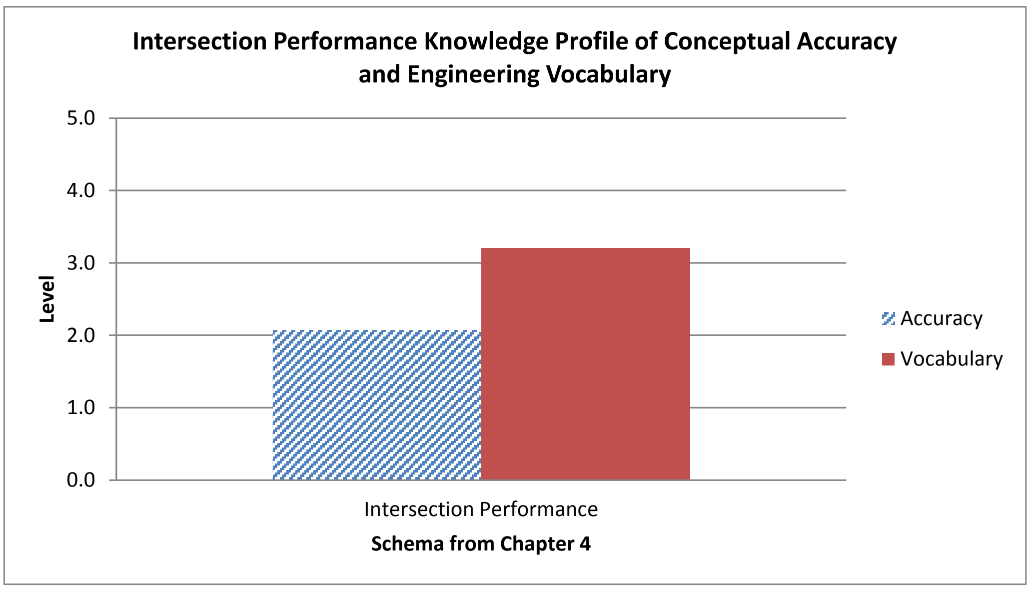


Figure 5.9: Intersection performance knowledge profile

- Intersection Performance
    - A far lower number of students produced a graph for performance than those that made a graph for departure flow with 11 students saying they could not produce a performance graph. This is a significant finding because many of the students could have used the graph they produced for departure flow as a performance graph. For example some students chose to produce variations of the d/d/1 queuing model. This graph could be used to show both departure flow and performance in the form of delay or queue length.

- The accuracy associated with the student being able to identify which portion of their graph represented performance was an important finding. Similarly to the data associated with departure flow, the students that could identify elements of their graph were very accurate. Eleven students could very accurately identify this portion of their performance graph. This shows a distinct fragmentation; if they knew the graph they knew some conceptual aspects of it, versus the 11 students that could not produce a graph at all.

Discussion/Conclusion

Validation Experiment Summary Conclusion

Due to the differences in accuracy between the faculty experts, Grad 1, and Grad 2 it's difficult to pinpoint exactly at what accuracy level the students are performing based on the criteria in Figure 5.2. From examining the distributions between the Grad 1 and the faculty experts the accuracy level is most likely close to the criteria of level 3 outlined in Figure 5.2 where they mostly produce limited vague details.

With the similarities in the averages and distribution of the vocabulary assessment between the faculty experts and Grad 1 it's most likely safe to infer that the vocabulary of the sample of students is very close to the description of level 4 vocabulary outlined in Figure 5.2. The key result that should be focused on is that the faculty experts, Grad 1, and Grad 2 find that the students have higher conceptual accuracy than they do engineering vocabulary. This result is confirmed by examining the distribution as well in a side-by-side comparison of each validation assessment independently.

Knowledge Profile Summary Conclusion

A quoted portion of one student's response to a question summarizes the findings:

Student – *"I don't know. I'm not good with vocab. I can explain it kind of a little bit, but I can't remember the terms."*

The results matched the students quote exactly. The overall accuracy average for the entire sample for all schemas of 3.2 and engineering vocabulary level average of 4.0. All six schemas in the presented knowledge profiles showed that conceptual accuracy levels are higher than the vocabulary levels by approximately one level. Comparing these averages and trends with the results of the data validation experiment suggest that the trend in the data is valid. This means that while the majority of the students in the sample have some basic conceptual accuracy, they did so with very limited details and poor engineering vocabulary.

These findings are consistent with novice learner behavior found in cognitive science literature. Novice students are said to have isolated and unorganized categories and have trouble keeping track of what information goes with a particular model (17) (18).

Although these findings are consistent with novice learner behavior; the trend of higher accuracy than vocabulary is significant because of its importance to how students categorize transportation engineering knowledge. Specific vocabulary is a measure of a person's ontological classification (17). Vocabulary elements are the titles assigned to schema and respective categories whether they are isolated, well organized, engineer like, or non-engineer like. The results here show that students have a non-engineer type vocabulary and documented instances of students using personal driving experience as support for their answers. With this non-engineer like vocabulary they are able to answer engineering questions at a slightly higher accuracy level.

What is also of interest is that only three of the questions in the interview were directed at traffic flow, performance, and basic graphs which are concepts that receive relatively lengthy focus in the introductory transportation course. The other four questions were slightly more advanced and focused on actuated signal control concepts where they would receive little or no instruction in the introductory class. Since the trend found in the knowledge profiles for all schemas for the entire sample was the same regardless of the difference in the questions suggests that the students already have established schema for the type of knowledge they were asked of. Their knowledge schemas were most likely developed in the driving and riding culture.

Implications of Pre-existing Knowledge Classification

The literature in conceptual change states how difficult it is to change, restructure, and reorganize knowledge schema and indicates that conceptual change could take place over a relatively long period. People of college age who have lived in a society such as that of the United States will most likely have a large and well organized knowledge structure of the driving/riding processes. Transportation engineering vocabulary and concepts are alternative and simultaneously similar explanations of the driving process and some of it may be contradictory information to the students already well established schema.

Therefore, once a student is presented with this new information they almost have no choice but to put it in comparison with the strongest categorization they have and either accept or reject the new information (2) (12). Another concern in conceptual change is the impact of reassigning new categories to flawed schema. Depending on the relative strength of the schema if flawed it may take longer to restructure. Students in introductory transportation engineering courses have approximately one semester to adjust and reassign categories to their existing schema. Even less time to adjust per specific concept.

It must be addressed that these findings are derived from the responses of students making field observations. These were simple questions about function and process, but they were most likely out of context for the student. Students are more familiar with the context of calculation. All of these students were on track to graduate and were not failing their introductory transportation course. These findings suggest the difficulties that students may have explaining simple processes at possible entry level position job interviews. They may be able to calculate the correct quantities, but they will not be able explain the process in acceptable transportation engineering vocabulary. Their design abilities may be influenced by a driver perspective rather than the transportation system perspective.

In conclusion the study objectives were met. By following the research direction in Chapter 4, the analysis presented a knowledge profile as a measure that was more generalizable to the entire student sample as opposed to just the 15 documented instances of personal driving experience found in Chapter 4. The results here are only on a small exploratory case study but it provides strong evidence for further investigation with a much more focused and specially designed experiment to confirm. The findings from this research give further and strong support to investigate the seemingly more personal driver-like categories that exist in novice transportation engineering learners. Investigation should first focus on confirmation that these results be duplicated with another experiment.

Initially, better, refined, and more focused criteria for questions to extract specific schema and categories need to be developed. Research should focus on the current vocabulary that students use to answer questions. Then focus should be to extract the various word combinations and terms (driver or engineering) that can describe the same concept. The terms and phrases students use is a window to understanding the method by which their knowledge is classified. Identifying the current categories could help adjust curricula.

CHAPTER 6: DISSERTATION DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Discussion

The common theme in the previous chapters is the presence of personal driving experiences in the student responses. Personal driving experience was used by the participants as a means of support for their responses. Each of the chapters viewed this phenomenon in several different frameworks of educational and cognitive science. Chapter 2 used affordances, Chapter 4 used ontological knowledge structure, and Chapter 5 used knowledge profiles. The evidence of personal driving experience found in student responses suggest that students were using a personal driver-like categorization that seemed to exist at a higher priority than transportation engineering-like categorization. Evidence also showed that students were using driver-like vocabulary but seemed to have a more conceptually accurate categorization of some processes with this type of vocabulary.

The research presented in this dissertation provides evidence to support the claim that students categorize some signalized intersection operations concepts based on personal driver type pre-existing schemas. The research, however, does not consider whether this classification is useful or not useful to advancing their knowledge of transportation engineering. Therefore, further research needs to address the significance of this pre-existing classification for transportation engineering. Research in the field of conceptual change concludes that concepts and schema that are well established can be difficult to rearrange, misconceptions are more likely to happen, all of which makes conceptual change more difficult to achieve (1) (2) (12). Although previous studies show how a pre-existing ontological classification of knowledge can be damaging to further learning, there are some unique differences about transportation engineering concepts that are contradictory to those findings that needs to be addressed and investigated.

For example, Chi defines two types of robust misconceptions that occur when information conflicts at different lateral categories. Both types deal with processes. Referring back to Figure 4.1, the process tree has two types of processes: direct and emergent. A direct process is one “that usually has an identifiable agent that causes some outcome in a sequential and dependent sort of way” (12). An example would be a vehicle braking for a stop sign. The causal agents are all identifiable and must act sequentially for the vehicle to stop. The driver must make a decision to stop, apply force to the brake pedal, which in turn applies pressure to the hydraulic system, brake pads will then make contact with the rotor, and the vehicle is slowed to a stop. Because these actions must occur in that sequential order, it is, therefore, a direct process.

An emergent process, however, is one where all agents are of relatively equal status, achieve local goals, and act simultaneously. An example from the literature is a flock of flying geese in a V-formation. The geese are relatively on equal status, simultaneously flying, and are achieving a local goal of flying in the path of least resistance. The geese are ignorant of the emergence of the V-formation and the goal was not to create a V but to fly in the path of least resistance. Similarly, traffic flow is a highly emergent process. No driver sets out on their daily routine to create traffic flow. All vehicles are essentially of equal status, act simultaneously, and achieve the local goal of reaching a destination and are basically ignorant of the global pattern of traffic flow that emerges.

Robust misconceptions to student learning can occur when a process is miscategorized within the ontological tree. An example would be classifying an emergent process as a direct process. Research has shown that physics students often miscategorize heat transfer as a direct process instead of an emergent process (12). Other robust misconceptions to student learning occur when there is a complete ontological tree shift. An example would be classifying an emergent process as an entity or substance. Many examples have been documented of this type of ontological shift in cognitive science literature. Chi reported on a study where students explained thrown objects slowing down because they “use up all the force”. The students talk about force as if it was a fuel like substance that can be consumed (12). Another example is when students talk about electric current as a flowing entity or substance (20).

Example of Traffic Flow as a Mandatory Misconception

Because traffic flow is an emergent process, all drivers act independently and simultaneously to achieve the local goal of reaching a destination. No driver sets out to create traffic flow, but with each simultaneous addition of an independently acting vehicle to a network, a global pattern of traffic flow emerges. By Chi's definitions of processes, traffic flow is definitely an emergent process.

In transportation engineering education and design, however, traffic flow is assigned units of vehicles per hour, idealizations of uniform flow, and saturation flow exists in design manuals and text books. These units and idealizations of traffic flow describe the emergent process as if it were a substance that can change state and be consumed. By Chi's definitions, classifying traffic flow as a substance category rather than the emergent process category is a categorical shift. Chi explains that this could be damaging to conceptual change but from the aspect of a transportation engineer it is a necessary misconception that needs to takes place. In order to have this type of conceptual change take place it would help to know the current classification the students holds in order to properly adjust the curricula to achieve educational goals. With the findings of personal driving experience presented in the preceding chapters it seems students have a pre-existing classification of signalized intersection concepts.

The transportation infrastructure, processes, vehicle system interactions, and social culture is a very large and significant portion of a person's life. Particularly so in the United States where at the very earliest, experiences of vehicle accelerations and decelerations take place during infancy. As the children grow they are carted around from place to place and assembling and processing interactions and behaviors of drivers, stopping and going for years before they finally reach an appropriate age and become an operating participant in these interactions. All that time spent self-exploring, establishing, and categorizing the driving culture and its processes in their own way long before any type of formal transportation engineering education. The findings presented in this dissertation's research suggest that this time has had an effect on student abilities to respond to questions about concepts they have recently been studying in their introductory course work.

Other transportation engineering educational studies have shown that introductory transportation student's explanations of sight distance and stopping sight distance calculations often result in a specific personal driving descriptions (1). The findings presented in this dissertation show that student categorization of signalized intersection concepts involve personal driving experiences as well. The majority of these personal driving experiences have been explained in a rather direct process type of answer. The student explains their driving situation in a sequential predictable order of events. Particularly these experiences were expressed during explanations of actuated signalized intersection operations where there are direct processes involved. But, when presented with questions that were more emergent process type, such as departure flow and intersection performance, their answers were limited in details and void of personal driving experience. These differences in the types of responses reflect their perception and categorization of driving experience gained throughout life.

As mentioned in the earlier example of the emergent process of the geese forming a V-formation; the goose does not know of the global emergence on the V. If geese could talk, the goose would most likely describe the situation as being a direct process of "the goose in front disturbs the wind for me and creates an easier flight for me". Here the student has been the goose longer than they have been the observer of the V-formation or put another way they have been a particle of traffic flow longer than they have been an observer of traffic flow. This pre-existing type classification of transportation knowledge is not necessarily wrong but is definitely in conflict with an emergent type of categorization or a substance type of categorization needed by the transportation engineer to solve the most difficult and trying problems in transportation engineering. Therefore, conceptual change must take place in order to understand the emergent global substance like processes. Cognitive science literature repeatedly explains the difficulties in achieving conceptual change with strong pre-existing ontological categorizations.

Conclusions and Recommendations

The research presented in this dissertation does provide sufficient evidence that students are likely to be significantly influenced by their experiences in the driving culture and this experience impacts their ability to categorize transportation engineering concepts. This phenomena must be explored further to help transportation engineering education become better equipped to produce better prepared and high quality entry level engineers. Presented now is a bulleted list of what educators and researchers can take from the work presented in the preceding chapters and what is recommended based on this work.

Educators

- Transportation engineering educators must help students achieve conceptual change by restructuring and categorizing transportation engineering knowledge. To help students achieve that, educators need to understand that there are different types of categorizations for certain processes of transportation engineering. Some concepts need to be direct while others need to be emergent. A personal driving experience is most likely classified as a direct process. In some cases the educator may need to facilitate a change from direct process organization to an emergent one.
- Students come to transportation engineering classes with a vast knowledge set that is gained primarily from their driving experience. This pre-knowledge set can contain valuable insights for understanding different traffic phenomena, but can also contain some level of misconceptions. Traditional teaching methods, where theory is the major focus, lack in opportunities for students to use their pre-existing knowledge set to resolve misconceptions. The results from Chapter 2 offer an example of some positive ways in which material can be delivered to students in order to restructure their conceptions. One way is to use traffic observation as a means of showing students the emergent type of classification. Direct observation of traffic is a promising way to show rather than tell students that traffic must be analyzed as a system that operates all the time. Also educators should develop activities where the students are required to vocalize the engineering terms in their appropriate context.

- Educators need to also consider how conceptual change takes time and how people are resistant to re-categorize or develop a new categories if their pre-existing schema are strong (12). Therefore, it is critical to re-examine the amount of material presented and how it is presented in introductory transportation engineering course. Typical curriculums at the introductory level spend a relatively small amount of time on many concepts. In the span of a semester a student will cover vehicle braking characteristics, geometric design, pavements, traffic flow, Highway Capacity Manual procedures, intersections, planning, and more. That is a considerable amount of information in a short amount of time and most of the information does not offer support for the other topics. Most learners would not achieve much conceptual change if any depending on the strength of their pre-existing categorization. Because students need more time to reorganize their categorizations in order to help them think like a transportation engineer, the amount of material introductory level courses should be reduced.

Researchers

- Viewing and assessing the phenomena described here is new to transportation engineering education and there is no datum of reference. Further research needs to establish this datum by conducting studies to repeat the findings presented here.
- Work should be done to identify the direct or emergent processes that take place in transportation engineering. Future research should establish where a direct process organization style of learning is more beneficial to an emergent and vice versa.
- Research should be conducted on how to implement theses findings to adjust and develop curricula that considers the challenges of conceptual change and helps students be better prepared for the engineering practice.

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APPENDIX 1

University of Idaho

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November 26, 2014

To: Michael Kyte

Cc: Howard Cooley

From: Leontina Hormel
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

Title: 'Deployment and Assessment of a New Educational Paradigm for Transportation Professionals and University Students'

Project: 12-371
Approved: 12/18/14
Expires: 12/17/15

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the **second-year extension** of your proposal is approved as offering no significant risk to human subjects as no changes in protocol have been made on this project.

This is a second year extension of approval and is valid until the date listed above at which time a new protocol will need to be requested if you are still working on this project. If not, please advise the IRB committee when you are completed. Should there be any significant changes in your proposal within the year, it will be necessary for you to resubmit it for review.

Thank you for submitting your extension request.

Leontina M. Hormel

Leontina Hormel