COMPARISON OF STUDENTS' AND PRACTICING ENGINEERS' KNOWLEDGE IN TRAFFIC SIGNAL ENGINEERING

By

KELVIN B. DARATHA

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

WASHINGTON STATE UNIVERSITY
Department of Civil Engineering

MAY 2013

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of KELVIN B DARATHA find it satisfactory and recommend that it be accepted.

____
Shane Brown, Ph.D., Chair

____
Haifang Wen, Ph.D.

____
Michael Kyte, Ph.D.

ACKNOWLEDGMENT

I would like to thank Dr. Shane Brown, Dr. David Hurwitz, and Rabiul Islam for helping me conduct the research and for pointing me in the right direction on this thesis. I would also like to thank all of the practicing engineers and students who agreed for an interview, in which the data from this study came from.

COMPARISON OF STUDENTS' AND PRACTICING ENGINEERS' KNOWLEDGE IN TRAFFIC SIGNAL ENGINEERING

Abstract

by Kelvin B. Daratha, M.S.
Washington State University
May 2013

Chair: Shane Brown

The current literature suggests that conceptual understanding, misconceptions, and the context of knowledge are important for the learning of students. Furthermore, the literature indicates a difference in the thinking between novices and experts. However, no research has been conducted to characterize the conceptual thinking of practicing engineers or to investigate practicing engineers' misconceptions and their comparison with students. Research is needed to determine the correct context for students in the engineering classroom, which would foster an environment with greater authenticity that would mimic the engineering practice.

This study used clinical interviews to extract misconceptions and contexts quotations from the interviewees, and compared the data between novice students, expert students, and practicing engineers.

The results of the misconception prevalence and the context of the concepts were used to compare the knowledge of traffic signal engineering between the three cohorts. The investigation of the misconception prevalence revealed that most of the concepts did not follow the trend hypothesized by the researchers. Furthermore, the results of the misconception prevalence also revealed frequent misconceptions across the three cohorts. The investigation on the context

prevalence revealed that the three cohorts generally followed the trend hypothesized by the researchers. Additionally, the novice students generally discussed the concepts in the context of their driving experience, the expert students discussed the concepts in the context of their advanced coursework, and the practicing engineers discussed the concepts in the context of their engineering experience. As a result, the three cohorts discussed the concepts in different contexts.

Consequently, engineering curriculums should present concepts in the context of how engineers use the concepts in the real world to foster students to think about the concepts in a similar fashion as engineers. This would result in engineering students who are better prepared for the engineering workforce.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

A significant effort among engineering educators and engineering education researchers has been committed to research on conceptual change theory. Most of this effort is related to the investigation of students' preconceptions and misconceptions, including the development of numerous concept inventory instruments (ciHUB 2011). Such efforts have drawn significant attention to the things that students' do not know (misconceptions) and teaching efforts to guide students toward correct understanding of engineering concepts (Krause 2012). However, research investigating practicing engineers' misconceptions and their comparison with students has not yet appeared in the literature of conceptual change theory. Conducting such research would provide valuable information for designing engineering curriculums.

Educational researchers in fields such as situated cognition and engineering practitioners have argued that the context of learning and application of engineering principles is central to being prepared for the engineering workforce (Lave 1991). The formation of new knowledge is attached with the context in which it is taught; the teaching of knowledge needs to be in the applicable conceptual and social context in which it would be used; and the application of the knowledge within a particular context may not be utilized if the learning occurs outside of the proper context (Brown 1989). In a practical sense this means that if the goal of engineering programs is to adequately prepare students for the workforce, then the context in which they learn should be similar to that in which the learned knowledge would be applied in the engineering workforce. However, most engineering programs continue to focus on equations, numbers, problems with single answers and passive means of learning. A portion of the reason for this approach may be a lack of understanding of how engineers utilize core engineering concepts and the contexts to which they relate and apply these concepts in engineering practice.

The purpose of this study is to investigate engineering students' and practicing engineers' knowledge of traffic signal engineering concepts. The study will consider the misconceptions and contexts of concepts of traffic signal engineering across three cohorts, including undergraduate students, graduate students, and practicing engineers who are actively engaged in the planning, design, or operations of traffic signals. Results from this study provide information that can improve the quality and effectiveness of learning in engineering classrooms concerned with traffic signal engineering.

LITERATURE REVIEW

This section investigated the existing literature important for the current study. This section investigated the importance of conceptual understandings and misconceptions for student learning. Furthermore, the section investigated if there were differences in thinking between novices and experts. This section also identified the gaps in the present literature. Finally, the research hypothesis for the current study was presented.

Conceptual Understanding

In general, successful engineering students are not the students who simply 'plug and chug' values in an equation, but are the students that have a grasp on the conceptual ideas behind the equations. These conceptual ideas are the backbone of a subject area and provide the foundation for the equations and the techniques to solve the specific problem (Richardson 2003).

As a result, students who fail to understand the conceptual meaning behind subject areas are forced to memorize the equations and the techniques to solve the specific problems (Richardson 2003). Thus, the students who memorize the way to solve problems to get a good grade in an engineering course are most likely not going to be great engineering students or professionals, because of their lack of the fundamental conceptual knowledge. This can partially be explained by misconceptions. For example, a study in the area of physics alleged that the pupil's initial understanding of motion resulted in a large influence on the student's performance in the physics course (Hake 1998). Furthermore, the study went on to include that traditional lecture instruction caused only a small change in the initial misconceptions of the students (Hake 1998).

Another study explained that students are much more skilled at solving mathematical computations versus the conceptual understanding that is required for flexibility and faster learning in the future (VanLehn 2009). Thus, engineering courses should be more geared to communicating fundamental engineering concepts, so engineering students have a deeper understanding of the foundations of equations and engineering processes.

In addition, students who learn the concepts of a field would become better professionals in that particular field. The reasoning behind this statement is that the better professionals would be able to adapt to variations in a problem presented to the expert. The understanding of concepts would help assist a person to perform better in an atypical situation (Van Merriënboer 2009). In order to further defend the claim that conceptual understanding increases professional performance is that certain large difficult tasks require a deeper understanding than simply facts and procedures, so a student of the field can evaluate when it is necessary to change the current procedure and when it is necessary to apply certain procedures (Mayer 2009). The student increases this knowledge of modifying procedures by understanding the concepts which are practiced by experts in the field (Mayer 2009). Furthermore, a study by Chi explained that there are two types of experts; routine experts and adaptive experts (Chi 2011). Routine experts become very skilled at a particular task and can solve problems that are similar to the task in which they are skilled (Chi 2011). Thus, routine experts have a procedural understanding of the task, which allows them to follow a procedure to solve a problem (Chi 2011). However, a routine expert would not know how to handle a problem if the conditions of that problem change (Chi 2011). In contrast, an adaptive expert has a conceptual understanding of the problem, and can use their conceptual understanding of the original problem to solve a problem if the conditions change (Chi 2011). Therefore, an individual with a conceptual understanding of a problem has an advantage over an individual who simply memorizes a procedure, because the person with the conceptual knowledge would have a greater likelihood of figuring out a problem in an event the original problem changes. In conclusion, students would become better experts in their field if they contain a conceptual understanding in their area of study.

As a result, the literature suggests that the conceptual understanding and misconceptions are important for the learning of students. Thus, the conceptual understanding of engineering concepts that are used by practicing engineers and identifying student misconceptions would be beneficial for students.

Differences between Novices and Experts

An expert is defined by Chi as “someone who is relatively more advanced, as measured in a number of ways, such as academic qualifications, years of experience on the job, consensus among peers, assessment based on some external independent task, or assessment of domainrelevant content knowledge" (Chi 2011). Thus, experts are quite familiar with the field, whereas a student is relatively new to the particular domain of the field.

One particular study sought to determine the differences between novice students and advanced graduate students in the area of physics (Chi 1981). The study asked the two cohorts to categorize a set of physics problems based on the similarities (Chi 1981). The study found that novice students largely grouped the physics problems by the concrete elements that were noted in the problem (Chi 1981). An example of this type of grouping is the categorization based on if the problem dealt with round disks, inclined planes, pulleys, or friction (Chi 1981). In contrast, the study found that the graduate students grouped physics problems by the underlying principles of the problem (Chi 1981). For example, graduate students based their categorizations on the way to solve the problems, such as energy, work lost, or by Newton's Second Law (Chi 1981). Interestingly enough, the method in which graduate students grouped problems resulted in lumping problems together that had different concrete elements (Chi 1981). This study used the task of grouping the physics problems to show the way in which the students represented the problem. Thus, the study showed that the expert students represent problems by the principles in which the problems can be solved, whereas the novice students represented the problems based on the elements described in the problem (Chi 1981). As a result, this study showed a difference in the way novice students and graduate students thought about problems in the field of physics.

Early studies in the education field concluded that experts had better search strategies than novices when it came to solving problems. One study concluded that the difference between experts and novices is the way in which the two groups search for the solution (Simon 1978). This early study's conclusion assumed that the representation of the problem between experts and novices were the same (Chi 2011). However, later research revealed that this assumption is not valid for academic domains in which the subject area is lush in knowledge (Chi 2011). As a result, the differences in knowledge between experts and novices enabled the two groups to have a different representation of problems, which contributed to different search strategies (Chi 2011). As a result, the prior knowledge contained by an individual is key for the search strategy the individual would take to solve a problem.

The current literature suggests that experts have a different way of representing a problem as compared to novices. This difference in representation can be attributed to the fact that experts contain more structured knowledge (Chi 2011). As a result, the differences in searching the solution to a problem were determined from the difference in which the experts and novices represented the problem (Chi 2011). As a result, the way in which problems are represented is an indicator on whether the individual is an expert or a novice in the field.

Experts and novices were shown to think differently in yet another study. This study compared the responses by historians and students when asked to select the most accurate paintings (Wineburg 1991). The historians selected their results by incorporating both the visual representations of the painting and the written documents (Wineburg 1991). In contrast, the students would select their responses based off the quality of the artwork, including realism and the detail of the artwork (Wineburg 1991). These results conclude that the historians (experts) representations were more integrated than the novice students (Chi 2006).

Understanding the differences in representations of problems is important for the learning of students. For example, the representation of teachers would be based on a correct and deep understanding of the topic in which they are trying to teach to the students (Chi 2011). In contrast, a student's representation of a topic would be based off of a naïve, shallow, and incomplete understanding of the topic (Chi 2011). If the difference in representations of a topic is ignored, then it is very likely that students would misinterpret the teacher's description of the topic (Chi 2011). As a result, students may form misconceptions from misunderstanding the teacher's explanation.

As a result, several studies have shown that there are differences in thinking between novices and experts. However, none of the previous studies were investigated in the field of engineering.

Gaps in the Literature

In conclusion, the literature suggests that conceptual understanding, misconceptions, and the context of knowledge are important for student learning. Furthermore, the literature indicates a difference exists in the thinking between novices and experts.

However, gaps in the literature were identified. In fact, no research has been conducted to characterize the conceptual thinking of practicing engineers. Understanding the conceptual thinking and context of practicing engineers could help instructors teach concepts in the correct context for those concepts that are used in the real engineering world. In other words, it would be beneficial for instructors to know how concepts are used in the real world. Thus, it is necessary to determine the correct context for students in the engineering classroom, which would foster an environment with greater authenticity that would mimic engineering practice. Furthermore, the literature does not contain any research investigating practicing engineers' misconceptions and their comparison with both novice and expert students. Conducting such research would provide valuable information for developing and designing engineering curriculum, specifically for traffic signal engineering.

Research Hypothesis

The researchers established three hypotheses for this study involving the comparison of knowledge of traffic signal engineering between novice students, expert students, and practicing engineers. First, the researchers hypothesized that the misconception prevalence would be highest for the novice students and lowest for the practicing engineers. Second, the researchers hypothesized that the prevalence of the context would be highest among practicing engineers and lowest among novice students. These two premises were made because it is expected that the knowledge level would increase from the novice students to the graduate students, and from the graduate students to the practicing engineers. The increase in knowledge would decrease the amount of misconception quotations and would increase the amount of context quotations that the interviewee discusses. Third, the researchers hypothesized that the practicing engineers would discuss the traffic signal engineering concepts in a more applicable context for engineering practice than the students. This claim arises from that fact that engineers practice in the real world and apply the concepts regularly. The study results will evaluate if these hypotheses were correct.

METHODOLOGY

The current study was designed to compare the knowledge of traffic signal engineering between novice students, expert students, and practicing engineers. Several key terms are presented below that help understand this study design.

Interviewee: An individual who agreed to participate in an interview for the study.

Cohort: A group of interviewees based on the amount of experience they had in traffic signal engineering. There were three cohorts in this study, including novice students, expert students, and practicing engineers.

Misconception: An interviewee provided an answer that was wrong, but the interviewee believed was correct.

Context: Interviewees discussed ideas, experiences, or concepts that were related to traffic engineering concepts. Furthermore, a context is information that goes beyond a basic 'textbook definition.'

Interview Protocol Concept Selection

The first step to compare the knowledge of traffic signal engineering between the cohorts was to determine the traffic signal engineering concepts to construct interview protocols. This step involved experts in the field of transportation engineering from around the country to collaborate in the selection of concepts, with the use of four webinars. Each webinar consisted of four experts, who were divided into the different webinars based on the expert's availability. Each webinar group was asked to complete an exercise before attending the webinar. This exercise asked the expert to individually brainstorm important traffic signal systems concepts and to place each concept into one of three categories: enduring understanding, important to know and do, and worth being familiar with. Each webinar group's individual expert responses were consolidated into a single list without the three tier categorical scheme. Thus, each webinar group had its own unique list of concepts prior to the webinar. During the webinar, the experts discussed the importance of each of the concepts that were on the list generated before the webinar. Once a consensus among the discussing experts was reached on the importance of a particular concept, then that concept was placed into one of the three categories. This process of building consensus among experts is commonly referred to as a modified Delphi Process. In conclusion, four different importance rankings for traffic signal engineering concepts resulted from the four webinars.

The next step in the process was to analyze the results from the webinars. The analysis required the concepts to be ranked, so a comparison could be made between the topics of isolated signals, coordinated signals, and networks of signals, which were discussed in the webinars and to consolidate the results across the webinars into one list. As a result, a decision tree was formed to establish the rankings based on the three categories of importance and based on the amount of webinars that the concepts appeared (Appendix A: Concept Decision Tree). The ranked concepts resulting from the decision tree logic are also presented (Appendix B: Prioritized Concepts from Expert Webinars). In conclusion, the data from the webinars resulted in a prioritized list of concepts important in the field of traffic signal engineering.

The next step was to determine the concepts to be used in the study. Both of the priority one ranking concepts were selected, but only two of the six priority two concepts were selected. However, three of these concepts revolved around signal timing of a coordinated corridor and were indirectly placed in the signal timing section of the interview protocols. The queuing theory concept was left out of the study, because of time constraints for the amount of material that can be covered in an interview protocol. As a result, four concepts were selected from the prioritized concepts to construct the interview protocols in this study.

Interview Participant Selection

The novice student cohort included 17 undergraduate students from Washington State University (WSU). Novice students were categorized as students who have taken the introduction to transportation engineering course, or were currently taking the course when interviewed. The novice student cohort interviewees had no advanced course work in traffic engineering at the university level.

The expert student cohort was composed of 13 graduate students from Oregon State University (OSU). Expert students were categorized as graduate students who have taken, or were taking, at least one graduate course in traffic engineering.

The practicing engineer cohort included 24 practicing engineers. Due to the proximity of neighboring cities to WSU and OSU, the clinical interviews were divided between Spokane, WA and Portland, OR. One researcher interviewed 10 engineers in the Spokane, WA metropolitan area and the other researcher interviewed 14 engineers in the Portland, OR metropolitan area. Both researchers followed an identical interview protocol for the practicing engineers interviews, to ensure consistency in data collection. Both private and public sector engineers were interviewed, with an average of 7.5 years of work experience in the field. Furthermore, the engineers had a median work experience of 5.5 years, and a range from 1 year to 28 years of work experience. The duration of one of the engineer's work experience was unknown.

As a result, three cohorts were associated with this study. The knowledge of traffic signal engineering was compared between the novice students, expert students, and practicing engineers.

Interview Protocols

The next step of the process to compare the knowledge of traffic signal engineering between novice students, expert students, and practicing engineers was to interview the three cohorts. The interviews allowed the researchers to determine the misconceptions and contexts that the three cohorts had with the important concepts selected from the webinars. As such, the concepts selected from the prioritized list of concepts generated from the webinars were used to construct interview questions. An identical interview protocol was used for both the practicing engineers and the expert students, because it was anticipated that the expert students would be familiar with the technical terminology in the protocol (Appendix C: Practicing Engineers and Expert Students Interview Protocol). In contrast, the novice students were not anticipated to possess a working knowledge of the technical terminology, thus an interview protocol was written for the novice students (Appendix D: Novice Students Interview Protocol). The questions were written in such a way that technical terminology was removed for the novice students interview protocol. In this manner, the novice students were able to demonstrate their knowledge of the traffic signal engineering concepts, without having to know the technical terms. If this technique was not used and the novice students used the same interview protocol as the other two cohorts, then it would have been likely that novice students would not have been able to produce useful responses. For example, a student may simply answer, “I do not know,” when faced with technical terms in which they are not familiar with, and this answer does not provide valuable information regarding misconceptions or contexts. Consequently, certain technical concepts were not reported in the results for the novice students. If the actual number of novice students with misconceptions for these technical concepts were included, then the study results would show that novice students have really low prevalence of misconceptions for those concepts. In reality, they have limited knowledge of these concepts. Consequently, the results tables show “N/A” for these technical concepts for the novice student cohort. The novice student interview protocol was tested with three pilot interviews to ensure that the protocol was useful. As a result, two interview protocols were used in the study.

The practicing engineers' and the expert students' interviews were designed for 45-60 minutes, and the novice students' interviews were designed for about 30 minutes. The interview protocols were designed as semi-structured and open-ended interviews. The open-ended interview styles were preferred, because the interview participants were free to answer without the possible "influence of predefined response categories" (Brown 2013). Thus, interviewees were free to say what they wanted about the interview questions. Furthermore, the interviews were semi-structured so that a consistent protocol was used and the interviewer was allowed to ask additional questions to extract responses. As a result, the interviews allowed the data collection of the interviewees' knowledge of the concepts on traffic signal engineering.

Although there are several methods to collect data, clinical interviews were chosen as the source of data collection in this study. The provocation of verbal responses from participants is one of the most common techniques to extract information in research on expertise (Chi 2006). Furthermore, Cooke mentioned that one method of verbal reporting is to ask questions in an interview, and use the participants' answers as the means of verbal reporting (Cooke 1994). In addition, interview questions are generally written to focus on specific topics and contain a specific sequence of the questions (Hoffman 2006). The interviews in this study complied with these explanations. To conclude, the structure of the interview protocols in this study were constructed on the basis of prior knowledge of data collection.

Interview Analysis

After the interviews were conducted, audio recorded, and transcribed, the next step to compare the knowledge of traffic signal engineering between the three cohorts was to analyze and code the interviews. Interview coding is a way to attach comments (codes) to a selection of texts (quotations) in a transcribed interview. The coding process was coordinated between two researchers at two different locations, so the interviews could be analyzed in a timely manner while producing comparable results.

The coding process was facilitated with the software Atlas TI (Muhr 2013). The first step was to allow the researchers to become familiar with the transcriptions and to figure out the coding process, and was performed by allowing both researchers to code a few interviews independently. The two researchers discussed the codes that they used while coding the interviews. The two researchers formed a standard in which to code misconceptions and contexts. The standard coding included three pieces. The first piece was the primary code. The second piece was to indicate whether the code was a misconception or context. Please note that the researchers actually used the word 'concept,' instead of 'context' during the coding process, although the 'concept' used in the coding is the same definition as the 'context' used in this study. The third piece was a description of the code. An example of the coding method is shown below in Table 1.

Table 1. Standard Coding Method.

Standard Coding	(Primary Code)-(Concept or Misconception)-(Code Details)
Example of Coding	Cycle Length-Coordinated-concept-Large side friction may warrant a half_cycle length in a coordinated corridor

The two researchers collaborated to produce a list of 58 primary codes (Appendix E: Primary Codes List). This standard coding process allowed the two researchers to code interviews in a similar way. As a way to make sure the coding between the two researchers would be similar, the two researchers analyzed the first interview independently and then collaborated to compare the quotations that they thought were misconceptions, contexts, or information to be ignored. The collaboration showed that the two researchers were analyzing the quotations in a similar fashion.

After the coding standard was set and the two researchers coding process was shown to be comparable, the interviews were divided up and analyzed independently. However, the two researchers collaborated throughout the process and were available to ask and answer questions when they arose. On average, the researchers discussed the project's progress at least once a week. This method was used to help ensure similar interview coding results from the two researchers.

After the interviews were coded, the codes were organized based on the cohort and if the code was a misconception or context. The codes were further organized based on the concept that the code discussed. The next step was to determine the number of times a code (same as the number of quotations) was used for each concept. A ratio of the number of quotations to the number of interviewees for that particular cohort (quotations-to-participation ratio) was used as a bench-marker for the most common misconceptions and contexts generated from the interviews. If the quotations-to-participation ratio exceeded 0.3, then the misconception or context was included in a summary table. The other cohort's quotations-to-participation ratio was included if at least one cohort generated a quotations-to-participation ratio greater than 0.3. Tables for comparing misconceptions and contexts by cohort while using the quotations-to-participation ratio were developed (Appendix F: Misconceptions and Concepts (Contexts) by the Quotes to Participation Ratio).

The next step was to determine the percent of interviewees who displayed a misconception or context for each cohort. Tables of the percent of people within a cohort that discussed a misconception or context for a particular concept were developed (Appendix G: Misconceptions and Contexts by the Percent of People within a Cohort). Furthermore, the concepts were divided into trends that existed between the cohorts prevalence. The final step involved the analysis of representative context quotations to determine the context in which the interviewee discussed the context quotations. This methodology allowed the comparison of knowledge of traffic signal engineering between the novice students, expert students, and practicing engineers to occur.

RESULTS

The results of this study were used to compare the knowledge of traffic signal engineering between the novice students, expert students, and practicing engineers. This section investigated misconceptions of concepts by displaying the misconception prevalence for each cohort and by separating the concepts based on the misconception trend between the cohorts. Representative misconception quotations were included to show misconceptions of the concepts for each cohort. Furthermore, this section compared the context prevalence of the cohorts for each concept. In addition, representative context quotations were analyzed to determine the context in which each cohort discussed the concepts. To sum up, the results of the misconception prevalence and the context of the concepts were used to compare the cohorts.

The goal of the misconception prevalence was to determine misconception trends between the cohorts and to determine concepts of high misconception prevalence. The prevalence of the misconceptions for all of the concepts is presented in Table 2. The table shows the percentage of the interviewees of each cohort who displayed a misconception for each concept, followed by the number of interviewees who displayed a misconception in parenthesis. The percentages listed in Table 2 reflect the percentages found in this study, and the study does not suggest that these percentages were the actual misconception percentages to the single decimal point in the whole population of the real world. Furthermore, Table 2 shows different trends that the concepts fit into regarding the prevalence of misconceptions from each cohort. As a result, the concepts could be separated into four misconception trends, with most of the concepts not following the misconception trend hypothesized by the researchers.

Table 2. Interview Misconception Data Results.

	Percentage of people with Misconception within Cohort (Number of People with Misconception in Cohort)			
	Misconceptions of Concepts:	**Novice Students (n=17)**	**Expert Students (n=13)**	**Practicing Engineers (n=24)**
Hypothesized Trend	Approach Speed	65% (11)	38% (5)	17% (4)
	Warrant References	65% (11)	23% (3)	0% (0)
	Cycle Length	47% (8)	54% (7)	17% (4)
Expert Students as the High Misconception Trend	Coordinated Characteristics	29% (5)	46% (6)	17% (4)
	Yellow Time	12% (2)	38% (5)	17% (4)
	Actuated Characteristics	18% (3)	46% (6)	25% (6)
	Vehicle Detection	18% (3)	54% (7)	13% (3)
	Phase	18% (3)	62% (8)	21% (5)
	Gaps	18% (3)	31% (4)	21% (5)
Reverse Hypothesized Trend	Min Green Time	N/A (1)	8% (1)	33% (8)
	Passage Time	N/A (0)	8% (1)	29% (7)
	Semi-Actuated	N/A (0)	31% (4)	42% (10)
	Vehicle Volume	12% (2)	23% (3)	21% (5)
Equal Levels of Misconceptions Trend	All-Red Time	35% (6)	31% (4)	29% (7)
	Effective Green Time	N/A (0)	69% (9)	67% (16)

The prevalence of the contexts for all of the concepts is presented in Table 3. The table shows the percentage of the interviewees of each cohort who discussed a context for each of the concepts. However, none of the cohorts discussed enough context quotations to reach significant context prevalence for the concepts of warrant references, gaps, passage time, and semi-actuated signals and is represented by dash marks (-) in the table. Most of the concepts that reported context prevalence followed the hypothesized trend of the novice students reporting the lowest context prevalence and the practicing engineers reporting the highest context prevalence. In fact, only two concepts resulted in trends that opposed the hypothesis by having the expert students as the lowest context prevalence (or tied as the lowest). Furthermore, practicing engineers had the highest context prevalence for the concepts reported in the table. As a result, the three cohorts generally followed the trend on context prevalence hypothesized by the researchers.

Table 3. Interview Context Data Results.

Misconception Trend:	Percentage of people with Context within Cohort			
	Contexts of Concepts:	Novice Students (n=17)	Expert Students (n=13)	Practicing Engineers (n=24)
Hypothesized Trend	Approach Speed	24%	15%	33%
	Warrant References	-	-	-
	Cycle Length	6%	31%	63%
Expert Students as the High Misconception Trend	Coordinated Characteristics	18%	31%	50%
	Yellow Time	0%	23%	25%
	Actuated Characteristics	0%	8%	38%
	Vehicle Detection	12%	15%	38%
	Phase	0%	0%	21%
	Gaps	-	-	-
Reverse Hypothesized Trend	Min Green Time	N/A (18%)	15%	38%
	Passage Time	-	-	-
	Semi-Actuated	-	-	-
	Vehicle Volumes	6%	8%	50%
Equal Levels of Misconceptions Trend	All-Red Time	6%	15%	25%
	Effective Green Time	N/A (0%)	8%	29%

The context quotations discussed by the interviewees enabled the study to determine the context in which the concept was discussed. Table 4 shows a summary of the context in which the concepts were discussed for each cohort. A dash symbol (-) was used if the context for the concept discussion was inconclusive. The novice students generally discussed the concepts in the context of their driving experience. The expert students discussed the concepts in the context of their advanced coursework. And the practicing engineers discussed the concepts in the context of their engineering experience. As a result, the three cohorts discussed the concepts in different contexts.

Table 4. Summary table on how the context of the concept was described

Context in which the concept was described: Summary Table			
	Novice Students	**Expert Students**	**Practicing Engineers**
Approach Speed	Driving Experience	Advanced Coursework	Engineering Experience
Warrant References	-	-	Engineering Experience
Cycle Length	Driving Experience	Advanced Coursework	Engineering Experience
Coordinated Characteristics	Driving Experience	Advanced Coursework	Engineering Experience
Yellow Time	-	Advanced Coursework	Engineering Experience
Actuated Characteristics	-	Advanced Coursework	Engineering Experience
Vehicle Detection	Driving Experience	Advanced Coursework	Engineering Experience
Phase	-	-	Engineering Experience
Gaps	-	-	Engineering Experience
Min Green Time	N/A	Advanced Coursework	Engineering Experience
Passage Time	N/A	-	Engineering Experience
Semi-Actuated	N/A	-	Engineering Experience
Vehicle Volume	Driving Experience	Advanced Coursework	Engineering Experience
All-Red Time	-	Advanced Coursework	Engineering Experience
Effective Green Time	N/A	Advanced Coursework	Engineering Experience

The rest of this section displays quotations that were representative of the misconception quotes and context quotes for each cohort within each concept. Example misconception quotations were presented to provide an example of the misconceptions displayed by the interviewees. Tables were developed that list all the misconceptions discussed in the study, by providing the code details for the misconceptions (Appendix H: Misconception Code Details). Since the representative quotations were taken as 'typical' responses from the interviews, the context quotations were used to determine the context that the interviewee discussed the concepts, leading to the results in Table 4.

Approach Speed

The approach speed is used to determine the stopping sight distance for a traffic signal. Thus, the approach speed can influence the placement of a signal. The approach speed is taken as the 85th percentile speed, provided either empirically or by adding around 5 mph to the posted speed limit.

This novice student displayed a misconception by inaccurately saying that the average vehicle speed is used when asked about how to determine the vehicle speed.

*Novice Student: Maybe go a quarter mile back, or something, and just use a radar gun, **and average it out**.*

This expert student displayed a misconception by indicating the average vehicle speed is used for traffic signal justification.

*Expert Student: I think one of the factors would be the accident rate at that area, **the average speed,** and you know it reminds me of the nine things that we should check to*

This practicing engineer displayed a misconception by saying that the posted speed limit represents the 85th percentile speed. However, the posted speed limit does not represent the 85th percentile speed of the vehicles on the roadway.

*Practicing Engineer: It's usually based on the 85th percentile speed, which is measured, or **typically the posted speed of the roadway facility**.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

The correction of the approach speed misconception would benefit the safety of traffic signals, because the approach speed is used for the stopping sight distance and the clearance interval. Furthermore, addressing the approach speed misconception in the classroom would be beneficial for students to understanding the applications of the approach speed in the engineering world.

This novice student discussed safety issues with traffic signals on high-speed intersections. Furthermore, this novice student identified a traffic signal that was located on a high-speed facility that the student felt was frustrating, suggesting the response was discussed in the context of the student's driving experience.

*Novice Student: Mmm. I think that is considered. It's very rare that you see stoplights along long stretches of 60-degree roads. **I mean, going to Whidbey Island there is one, and it's also really, really frustrating, because then there's a bigger dilemma zone.** And so I think that they try to not stop people going 60, especially because if someone didn't stop and then hit cars going 60 it'd be bad, so safety issues...*

This expert student discussed that the 85^{th} percent speed is a reasonable speed to consider. The expert student provided a detailed reasoning for the approach speed determination, which was likely studied in the student's advanced coursework. Thus, the approach speed was discussed in the context of the expert student's advanced coursework.

Expert Student: Speed data would definitely be something you're going to want to look at. The speed of the approach I think, again, depending on what kind of budget you have you're going to grab the posted speed limit as a starting point. ***It'd be great to take some actual spot speeds in the field, and maybe get an 85th percentile speed. That's a pretty good design, a pretty good number for design. It's the upper end of what's reasonable. You obviously can't design a road for the outliers.***

Similarly to the expert student, this practicing engineer discussed knowledge on the approach speed. However, the practicing engineer goes one step further to explain why the approach speed is important for justifying signals. The engineer explained that approach speed influences the visibility of the signal and the possibility that the speed limit should be lowered to satisfy a safe visibility (stopping sight distance) for the signal. This quotation suggests that this engineer's response was in the context of engineering experience, because the engineer described the application of the approach speed in the field.

Practicing Engineer: The speed of the approach is typically what the posted speed is. Data is very important too. ***It might be posted 30 but the 85th percentile might be 40, 45, and that's important to know. Approach speed is very important especially if you have limited visibility; will the signal be adequately seen or not. If you're putting in a signal, you might need to reduce the speed limit on the corridor.*** *There's different things to consider.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Warrant References

The warrant references are used to determine if a traffic signal should be placed at an intersection. The Manual on Uniform Traffic Control Devices (MUTCD) explains the nine warrants which may be used to justify the placement of a new traffic signal.

This novice student displayed a misconception by indicating the references for signal justification are found in local, state, or federal codes. Although local governments may reference the MUTCD, the student does not understand the source for signal warrants.

> *Novice Student:* ***I can go to my local-- I mean it's all code-- coded per city, usually. I imagine there's also-- like, there's federal and then there's state codes****, but I think I feel, just from what I've seen from other various different departments or fields that I've been in, that there's also city-by-city codes. And you can always go to the public offices and ask for that data, if it's publically available.*

This expert student displayed a misconception by indicating that the Highway Capacity Manual provides traffic signal warrants.

> *Expert Student: Or a textbook that references the* ***Highway Capacity Manual****; I'm pretty sure.*

None of the practicing engineers displayed a misconception for warrant references. As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

If the warrant references misconception was fixed, then students would have a better understanding on how traffic signals are justified. Furthermore, engineering students would know how to determine if a traffic signal should be placed at an intersection. This knowledge would give the students a better understanding of traffic signals.

None of the novice students or expert students discussed a warrant references context quotation. This practicing engineer discussed that the local jurisdiction may have other considerations in addition to the MUTCD signal warrants. This engineer likely had experience in justifying traffic signals in practice. As a result, the engineer discussed warrant references in the context of engineering experience.

> *Practicing Engineer: Well justification in general for a signal needs to follow the MUTCD. MUTCD actually has warrant analysis guides for signals and for stop signs and based upon those, meeting that requirement, generally here in this jurisdiction in Spokane County, you need two or three of the warrants for signalization and then you're basically have that justification. If you're meeting one warrant, whether it be P in peak hour and maybe not so much ADT, then you have to actually look into the consideration of engineering judgment.* ***There is a lot of engineering judgment that falls in with the MUTCD that there is no manual for; it's what's safe, what is practical for the jurisdiction that you're working in****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Cycle Length

The cycle length is the amount of time it takes for a signal to serve all of its phases. An isolated signal should have a cycle length that minimizes the average vehicle delay for the intersection, while a coordinated traffic signal's cycle length must be the same or possibly half or double of the cycle length for all of the intersections on the coordinated corridor.

This novice student incorrectly said that the determination of the cycle length is the same for an isolated signal and a coordinated signal.

Interviewer: Does that process differ between an isolated intersection and an intersection that is located downtown, or is the same approach?

Novice Student: I'm assuming it'd be the ***same way****. Yeah.*

This expert student incorrectly mentioned that the speed and distance between intersections goes into the calculation of the cycle length for each intersection on a coordinated corridor.

Expert Student: You can factor that into the cycle length, based on when the last car is going to go through the previous intersection, and like, that-- the change is going to happen, ***then the distance and speed calculations go in the cycle length of the next one****, and then, you know, on down the road.*

This practicing engineer displayed a misconception by saying that the order of the phases influences the cycle length for an isolated intersection.

Practicing Engineer: So the cycling is I guess what contributes to that is the green time, the yellow time, and the red time for all of the different phases. ***I mean I guess it also depends on what order you have the phasing going in*** *and the green, yellow, red time assigned to each of those phases.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

If the cycle length misconception was corrected, then intersections would operate more efficiently. This would result in less time that vehicles would have to wait at an isolated signal and would allow coordinated corridors to operate more efficiently by allowing vehicles to progress through several traffic signals.

This novice student discussed that shorter cycle lengths should be used in a downtown grid, to prevent backups into upstream traffic signals. This novice student discussion on downtown cycle lengths was described in the context of the student's driving experience, because the response suggested that the student has observed backups in downtown areas and may have had the experience of waiting at a traffic signal for a long time.

> *Novice Student: Yeah, that would be tricky, especially in a downtown grid. I mean, I guess the way that I would probably think about it just as an initial guess would be if you're looking at the* ***-- it seems like if there's more traffic you'd want quicker cycles so that you could rotate people through more quickly because within a city block there's only so much room that cars can kind of cram themselves in there****, so you'd want to have quicker cycles so that you didn't end up with a backup that goes more than one block because if that happens, you'll have a green light and nobody's getting through it, so I imagine in a more urban area, you'd probably end up with quicker cycles.*

This expert student discussed that multiple variables go into determining the cycle length for an isolated intersection and the student likely studied the subject in an advanced traffic signal course, which suggests that the discussion was in the context of the student's advanced coursework.

> *Expert Student: All rules are made to be broken, but as a general rule of thumb, yeah, 120 seconds is pretty long at an intersection, so it's a balancing act. First off, you're going to want to know* ***the volumes that you have at the approaches****. If you have* ***long queues****, having a long cycle time is going to make the intersection more* ***efficient****, because each time we transition between phases we lose a little bit of useful time because we have to safely terminate the priority that one phase has, and then assign that priority to a different phase. And we're losing some, basically, time at the intersection with that* ***short all red phase, potentially, and the end of the yellow light, which may be unusable****.*

And then we're going to have some ***startup loss time*** *when that green switches, or is displayed to that new movement and they have to perceive and then react to that stimulus.*

This practicing engineer discussed that several considerations go into determining the cycle lengths for all of the intersections in a coordinated corridor. Although both the expert student and the practicing engineer discussed several variables for determining the cycle length, this practicing engineer discussed conditions in the field. This engineer talked about the controller in the field and that the engineer may have to adapt based on what existing equipment allows to be done. Thus, the engineer's discussion was in the context of the engineer's engineering experience.

Practicing Engineer: A lot of them feed into the selection of the cycle length for a corridor and so if I was starting from scratch the first thing I do is I enter in, you know, my ***pedestrian intervals and that basically gives me a starting point*** *so I know what my minimum cycle length is going to have to be,* ***unless my controller allows me to violate pedestrian intervals****, which we do sometimes if we have to, but I try not to do that because it throws the intersection out of sync. So yeah, so we start with that. Then I look at the* ***vehicle demand and try to find the shortest cycle length that will accommodate all of the intersections on my corridor****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Coordinated Characteristics

Coordinated characteristics are attributes that are associated with traffic signals that are coordinated with each other. Coordinated traffic signals are used to progress traffic through a corridor, and are very common in downtown areas.

This novice student displayed a misconception because the student explained that the first traffic signal in a coordinated corridor detects vehicles, and the rest of the traffic signals follow with the change of the coordinated phase from the first traffic signal.

> *Novice Students: I would guess that there would be **only one sensor determining all of the lights so at the first light there'd be a sensor** determining <inaudible> all the traffic or when there's someone at the light and then it'll change that light and then the next one and the next one and the next one until that person or a group of people can get through the light.*

This expert student displayed the same misconception in that the student explained that the first traffic signal in the coordinated corridor can use vehicle detection and the rest of the traffic signals would follow.

> *Expert Student: Yeah, you can't have actuation in a corridor, to my knowledge at least, because, like we talked about earlier, with that actuation it'll change your cycle length. And, I mean, I guess in a sense maybe you could **set-up actuation at the first signal in a progression, and then that would just control when that first signal terminates, and then it would pass that information on to all the other signals with the appropriate amount of delay**, but I don't know if that's done. I think it should be if it's not, but...*

This practicing engineer displayed a misconception on coordinated characteristics, by saying that coordinated signals are generally actuated. Coordinated signals can be set up in an actuated coordinated format, but those signals are not fully actuated. Most of the time, coordinated signals are pre-timed.

Practicing Engineer: ***Coordinated signals are generally actuated***

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

If the coordinated characteristics misconception was corrected, then coordinated corridors would operate more efficiently. The improved efficiency would result in fewer stops for vehicles of the progressive mainline.

This novice student explained that gridlock is more likely to occur if traffic signals are not coordinated. This novice student's response was in the context of the student's driving experience, because the discussion was described in a way that suggested that the student experienced non-coordinated signals that would cause backups and it was frustrating.

Novice Student: ***Well, like with the unconnected ones you could have a green light but the signal after that could have red and then there could be a backup*** *which then the light at the-- the first one that's green the cars aren't able to move because there's the backup which they can't cross the intersection.* ***And then that's a headache****. While the connected ones are also going and smooth.*

This expert student understands that there is more wasted green time in coordinated signals, because all of the intersections have to have the same cycle length. This expert student may have learned in advanced coursework that the cycle length used at a specific intersection along the corridor may not be the most efficient cycle length for that individual intersection, because all of the cycle lengths must be the same. Thus, the expert student discussed coordinated characteristics in the context of advanced coursework.

Expert Student: With an isolated signal, again, you can be more specific to its actual surroundings of how much volume it has, whereas in a corridor, I mean, you're ***stuck with a certain cycle length, so your effective green time may not be used as well*** *because that cycle length-- if it's determined for intersection A and you're at intersection B, that's not the ideal cycle length for that time.* ***You're going to have more wasted effective green time because you can't actually specifically plan for that intersection as far as your cycle length goes.***

This practicing engineer said that the cycle length and the offset are used for coordinated signals. Although a concise response, these are the two main components to coordinating signals. The brief correct response might be a show of confidence, because the engineer may have coordinated signals in the field. Thus the response was made in the context of the engineer's engineering experience.

Practicing Engineer: We have ***cycle length and offset****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Yellow Time

The yellow time informs drivers that a red light is about to occur. Thus, drivers should start to stop at the appearance of the yellow indication, unless they are too close to stop safely, then the drivers should continue through the intersection.

This novice student displayed a misconception by indicating that the yellow indication needs to be longer when the flow rates are high. In reality, the yellow time duration is independent of the flow rate.

Novice Student: You would definitely want it to be an actuated system because you don't want there to be a long green light when there's nobody coming. As well you would definitely want to make sure that there is a long period of yellow time because ***if there's a high flow people will most likely be rushing to get through the intersection; they want to-- so you would want a longer all red time, a longer yellow time*** *to make sure that the intersection is clear and safe for cross traffic to flow; things like that.*

This expert student displayed a misconception by indicating that the yellow time in a coordinated signal has to consider synchronized with other signals. Although the green times need to be synchronized in a coordinated corridor, synchronization does not go into the calculation for the yellow time.

Interviewer: So you're calculating the yellow time for an intersection, isolated intersection, and for an intersection in a coordinated corridor.

Expert Student: Well, again, because I'm not that much like familiar with that coordinated, so all that comes in my mind in coordinated signal, like it's synchronized with the other signals in the network. ***So my yellow time will have-- when I'm thinking about the yellow time in a coordinated signal, I have to think the synchronization****. Like a vehicle is coming, it has to stop or it has to proceed through the next intersection. So I have to keep those factors in mind. But an isolated signal, like if a vehicle-- if a vehicle-- say it's on yellow, like depending on its position in the intersection, it will not stop. Like I don't have to think of other factors here.*

This practicing engineer displayed a misconception by indicating that the calculation method based on speed can create an excessive yellow duration, which is an incorrect statement.

Practicing Engineer: That one, that can be policy, or some places set a fixed yellow-time policy, and some places use a calculation-based method and add some judgment on top of that because sometimes ***the calculation method based on your speed can create too much yellow time****. So I don't know. I think it's a policy decision.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

The correction of the yellow time misconception would result in safer traffic signal operations. The improved understanding of the yellow time would allow the yellow duration to be determined in the correct and most safe way.

None of the novice students discussed a yellow time context quotation. This expert student discussed that a yellow indication reduces the chance of a collision by warning the drivers, and the yellow time was probably studied in the expert student's coursework. Thus, this expert student's explanation was made in the context of advanced coursework.

Expert Student: I think it's just a pretty logical way to assign priority to different movements and then ***safely inform drivers that their priority is coming to an end and then stop them and allow another movement to have priority****. And, I mean, you know, if you didn't have that yellow light there, you can just imagine and intersection that's either red or green and the other side is red or green, so you're barreling along at 45 miles an hour and you're 20, 25 feet away from the intersection and it turns red, you can't stop in time and the other guy, his turns green and he jackrabbits off the line and all of a sudden you've got a pretty nasty crash.*

This practicing engineer discussed that a too short yellow duration and an excessive yellow duration both lead to bad outcomes. This engineer understands that an excessive yellow time can result in drivers to become more aggressive, and the engineer may have witnessed intersections in the field that had excessive yellow durations. As a result, the practicing engineer's discussion was made in the context of the engineer's engineering experience.

> *Practicing Engineer: It's more likely the characteristics of the intersection, the driver behavior, the vehicle mix, potentially trucks and other things like that, and again, it gets back to getting out there and seeing the operations to understand, is* ***my yellow time too long, is my yellow time too short. A lot of people tend to emphasize yellow times being too short, or all red times being too short, but there's an equally poor outcome that can occur from making your yellow times too long and your all red times too long, because drivers are smart, they can figure stuff out if it's perceivable to them, they'll start being more aggressive potentially.***

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Actuated Characteristics

Actuated characteristics are attributes that are associated with actuated signals. Actuated signals use detectors to detect vehicles that are waiting and/or approaching the intersection. This detection capability allows actuated signals to work much more efficiently than pre-timed signals in an isolated intersection.

This novice student displayed a misconception by indicating that the signal times the waiting time on a detector and the signal tries to minimize that wait time.

Interviewer: What does a signal do when it detects a vehicle?

Novice Student: ***I guess it times how long they've been waiting there and then makes sure that the wait time is minimized****, so it senses how fast people are going and projects the flow and says "Okay, so if there's this many people, then this time." My assumption.*

This expert student displayed a misconception by indicating that actuated signals work in a first come, first serve basis.

Expert Student: So I think again, I'm going to take that intersection as an exam, so it's kind of like I think it still is adopted ***the first approach first served rule for the signal, for the phase service****, yeah.*

This practicing engineer displayed a misconception by indicating that an actuated signal with low demand would default to a pre-timed signal.

Practicing Engineer: If it's an actuated signal that actually-- ***it's an actuated signal that isolated, that is not getting much demand, if anything at all-- then it defaults to pretimed****, dependent upon the controller, or whether it's <inaudible>.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

The correction of the actuated characteristics misconception may result in more efficient actuated intersections. This improvement in efficiency may result in lower vehicle delays for vehicles at actuated intersections.

None of the novice students discussed a context quotation for actuated characteristics. This expert student discussed that actuated signals work more like a pre-timed signal when experiencing high traffic volumes, and actuated signals were likely covered in the student's coursework. Thus, the expert student discussed actuated signals in the context of advanced coursework.

Expert Student: The upside is that you have an intersection that reacts to the actual traffic conditions at the intersection, so people... ***Well, under high-volume conditions, it's going to operate a lot like a pre-timed signal****, but under low-volume conditions, people won't have to wait as long, and that translates to, you know, savings in time for the drivers, savings on the environment because you're not burning gas idling at a red light.*

This practicing engineer discussed that an actuated signal with failed detection would lead to inefficient conditions. This engineer may have witnessed a detector that failed at an intersection, and may have seen the inefficiencies that resulted from the failed detector. As a result, this practicing engineer discussed actuated signals in the context of the engineer's engineering experience.

Practicing Engineer: You know, actuated control can actually be a negative if an agency is not willing to maintain their detection, or watch over it, because ***if an actuated signal with detection fails, it usually fails on, so it's stuck on, and that will create inefficient operations at the intersection****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Vehicle Detection

Vehicle detection informs the traffic signal controller that a vehicle is present over the detection zone. This information can either mean that a vehicle is waiting at the intersection, or is approaching the intersection. The detectors can be used at the stop-bar of an intersection or can be placed upstream of the intersection.

This novice student displayed a misconception by indicating that a vehicle gets in line to be served once it is detected by the signal.

Interviewer: What does a signal do when it detects a vehicle?

Novice Student: It probably ***puts it in line****, or whatever, within the whole cycle of signal A, B and C, or whatever. I don't know. I'm not explaining it very well right now.*

This expert student displayed a misconception by indicating that advanced detectors extend the yellow indication to let a vehicle cross the intersection.

Expert Student: I don't know; I guess it would be the advanced detector would detect a vehicle that was too close to the intersection to stop and would allow them to proceed through the intersection once the stop detector, you know, activated the-- so, start at the beginning, the car comes to a stop detector; starts the stopping process, but the ***advanced detector would detect a vehicle that was too close to the intersection to stop and would lengthen the yellow phase to let them proceed****; I think; I don't know that. That's my guess.*

This practicing engineer displayed a misconception by indicating that stop-bar detectors are not used to detect gaps between vehicles. Although some methods may not use the stop-bar detectors to detect gaps between vehicles, this engineer implied that stop-bar detectors are never used to detect gaps between vehicles.

Practicing Engineer: ***Well, the stop-bar just will tell you if anyone is sitting at the intersection waiting to be served.*** *But the advance detection is crucial for, like I said, in* *the detection of gapping out.* ***It's not looking at the stop-bar to tell what the headway is between vehicles***

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

Corrections of the vehicle detection misconception would improve the efficiency of traffic signals. A better understanding for vehicle detection would enable actuated signals to operate more efficiently.

This novice student discussed the consequences of a broken vehicle detector. This novice student explained an experience that the student had with a broken detector. As a result, this novice student discussed vehicle detection in the context of driving experience.

Novice Student: That doesn't always work, though, if there are sensors, because there's ***one light in Kirkland that the sensors broke and that you never, ever, ever get a green****. You have to just sit there****. I sat there for like 10 minutes*** *and then said "Well, U-turns are illegal" and went right and then went left.*

This expert student discussed that a longer detection zone means that a shorter passage time should be used, and this subject was likely studied in the student's coursework. Thus, this expert student's explanation of vehicle detection was in the context of advanced coursework.

*Expert Student****: Longer detector length, shorter passage time****. Well, I mean, the phase termination is, you know, the passage time is going to play into that phase termination, so once the passage time counts down, you're going to get that yellow. Like I said before, if you've got a really long detector, you don't need as large of a value for that passage time because you're able to detect cars over that 30- or 60-feet section as opposed to just having that 6-foot circle or something.*

This practicing engineer discussed that a longer detection zone could mean more max outs if the timing parameters are not adjusted to the longer detection zone. The engineer's explanation of including max outs suggests that the discussion of vehicle detection was in the context of the engineer's engineering experience. This was the case, because unnecessary max outs of the traffic signal may prompt people to complain to the engineer that the signal was poorly timed, because people would have to wait an unnecessary amount of time on the side streets. Thus, the explanation of including the max outs indicate that the response was in the context of the engineer's engineering experience.

> *Practicing Engineer: Well obviously the longer the detector the longer zone of detection you have so it's a lot easier to, depending on how you've got your parameters set up, you* ***could max out more often if you have longer detectors****. But I mean I think if you set your parameters accordingly and base your loop detectors placement, that doesn't have to necessarily be the end result. But yeah, I mean having a longer detector essentially creates a longer, effective detection zone.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Phase

A phase is a movement, or a set of movements, that run concurrently at an intersection. There are typically eight phases at an intersection (one through phase and one left turning phase for each direction on the intersection), although there are plenty of intersections that do not have eight phases.

This novice student displayed a misconception by indicating that the phase sequence is the same for all intersections.

Interviewer: So do you think that the sequence of who gets to drive through the intersection is the same for all intersections? Or do some intersections have a different sequence of who gets to go first?

Novice Student: Honestly, I've never paid attention to it. I would imagine that ***you drive forward, and then you've got the turn, and then the other direction goes****. In Colorado Springs they have a walk light, so everybody stops and the pedestrians just go, but that's the only thing I can think of is different.*

This expert student displayed a misconception by indicating that a phase is the color indication on the signal head, such as the green, yellow, or red indication.

Expert Student: ***A phase is the color indicator: the green, or yellow, or red****.*

This practicing engineer displayed a misconception by indicating that the phase split is the green time for a phase.

Interviewer: What is a phase split for an isolated intersection?

Practicing Engineer: ***Split time is more or less the green time of a phase****.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

Improvement of the phase misconception may result in more efficient signals, because engineers would have a better understanding on what is meant by a phase.

None of the novice students or expert students discussed a context quotation for phases. This practicing engineer discussed left turning movements, and is likely that the engineer had experience on permissive left turning in the field. As a result, the explanation on phases was in the context of the engineer's engineering experience.

Practicing Engineer: When you have ***permissive left turns especially flashing left arrows you need to be cognizant of the volumes of pedestrians that are conflicting with that movement because there is kind of different levels of permissive left turns*** *where if you're permitted to turn left on just a green ball that's people might look a little bit more carefully than if they have a flashing left turn arrow where they are kind of encouraged to seek a gap. Or if they have a protected left turn then they know they're protected and when they see the green arrow they know.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Gaps

A gap refers to a gap between vehicles while traveling along a roadway. Gaps are important to judge if a vehicle has enough time to enter the major roadway from a minor street in a non-signalized intersection.

This novice student displayed a misconception by indicating that gaps are not important for the decision of installing a new traffic signal.

Interviewer: ...do you think the gaps between the vehicles on the major roadway are important to know for the decision to installing a traffic signal?

Novice Student: I just think of when I out of my neighborhood onto the main highway, yeah, sometimes I don't judge the gaps well enough. And I'll pull out and I'll have to *speed up really quick, so I don't. Next person is going to be mad,* ***but I don't know how that helps in judging whether or not****.*

This expert student displayed a misconception by also indicating that the gaps between vehicles are not an important consideration for signalizing an intersection.

Expert Student: Because it also depend on, I mean, the distance between two adjacent intersections, you know, like any of those intersection are signalized, it's going to be really complicated gapping system there, so I'm not quite sure about that, but for the-- to install a signalized control into an intersection, ***I don't think the gap is the problem****, or is the kind of data we need to think of.*

This practicing engineer displayed a misconception by saying that part of a warrant is to determine the gap sizes of vehicles going through the intersection, so the left turning vehicles have room to make the turn. This information is important for signal justification, but gap sizes for vehicles are not directly a warrant in the MUTCD.

Practicing Engineer: Yeah. That's usually one of-- ***part of one of the warrants is to determine if left-turning vehicles have sufficient gap to make their movement safely and if there's sufficient gaps in the total traffic stream to allow the volume of left-turning traffic to proceed through the intersection****.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

Improvements in the misconception for gaps could result in better justifications for signals based on gaps. This could possibly lead to safer intersections, because non-signalized intersections may become signalized if the gaps to allow turns are rare and cause backups.

None of the novice students or the expert students discussed a context quotation for gaps. However, this practicing engineer discussed that drivers can make aggressive decisions after waiting 30-60 seconds to turn onto a road. The engineer most likely noticed this driver behavior by conducting observations in the field. Thus, the explanation on gaps was in the context of the engineer's engineering experience.

> *Interviewer: How would you use gap data for the decision of installing a new traffic signal?*
>
> *Practicing Engineer: I think gap data is very important for vehicles and pedestrians 'cause* ***if you don't have sufficient gap you can't get in traffic, and after about 30 to 60 seconds, which is not a lot of time but for drivers it's an eternity, then they start making rash decisions and that will lead to collisions so gaps are very important to see if they're adequate or not****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Minimum Green Time

The minimum green time for actuated signals provides a minimum amount of green time to an approach. The duration of the minimum green time is to allow the vehicles to overcome the start-up lost time and to allow the queue to reach the saturated headway.

This expert student showed a misconception by indicating that the purpose of the minimum green time is to give vehicles on the other approach more green time.

> *Interviewer: So what is the purpose of the minimum green time? Why is there a minimum green time?*

Expert Student: ***To let the traffic from the other approach use the intersection more****.*

This practicing engineer showed a misconception by indicating that the purpose of the minimum green time is to get at least a vehicle through the intersection. Although the result of the minimum green time may back up this claim, the purpose of the minimum green time for actuated signals is to provide a time that will cover the start-up lost time and allow the queue to reach the saturation headway. As a result, this engineer showed a misconception.

Interviewer: What is the purpose for the minimum green time?

Practicing Engineer: ***Pretty much to at least get somebody through the intersection****.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

Corrections of the minimum green time misconception would lead to more efficient traffic signals, because the minimum green time would allow the queue to get started and the minimum green time would not be unnecessary long.

This expert student discussed that the minimum green time serves driver expectations. The expert student likely studied minimum green time in the student's coursework. Thus, the expert student's discussion on minimum green time was in the context of advanced coursework.

> *Expert Student: Minimum green, <laughs> you have to give people, you know, a minimum amount of green time* ***to react just to clear the intersection and fulfill driver expectancy****. You don't want to, you know, have a car at the intersection, as soon as he drives off, that sensor switched to yellow. So it's just to have a minimum value to, you know, right, to be consistent with what drivers expect and, you know, maybe make sure you get at least one or two cars through the intersection.*

This practicing engineer discussed that hills or a lot of trucks can influence the minimum green time. The engineer explained that a standard minimum green time is typically used in practice, but certain conditions require a change to the standard. As a result, the explanation of minimum green time was given in the context of the engineer's engineering experience.

> *Practicing engineer: Depending on the speed and depending on the volume is what we set our maximum green times on and* ***our mins are typically 5 seconds unless there's like a hill or a lot of trucks****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Passage Time

The passage time is a timing parameter for actuated signals. The purpose of the passage time is to extend the green time to the current active phase when a vehicle is detected in the detection zone.

This expert student displayed a misconception by indicating that the passage time is used to extend the yellow duration if a vehicle is detected in the dilemma zone.

> *Expert Student: Based off of the presence of vehicle you can well I'm thinking of it in two manners; the first manner I'm looking at is based off presence of vehicles, you extend the green phase; the second one, or to maintain movement of, there's obviously a volume of vehicles maintaining it to maintain movements, the other vehicle extension timing that is jumping to mind is a safety by* ***detecting a vehicle within a part of the dilemma zone and extending a yellow phase to hope with the goal of clearing the vehicle before the red phase occurs*** *and I've seen that in mixed results <laughs>.*

This practicing engineer displayed a misconception by indicating that the passage time is the time required for a vehicle to travel from the advanced detector to the stop-bar detector.

Interviewer: What is the purpose for the passage time?

Practicing Engineer: ***Well, that's the time for the vehicle to pass from the upstream detector to the stop-bar****, I think.*

Interviewer: And so this term, passage time, would only affect-- you would only consider that when you have an advance detector?

Practicing Engineer: Correct. If you only have stop-bar detection then, yeah, there is no passage time.

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

Improvements to the passage time misconception would be an improvement to traffic signal design. A correction in the passage time misconception would result in gap outs occurring in the correct places, which would allow the traffic signals to operate more efficiently.

None of the expert students discussed context quotations for the passage time. This practicing engineer discussed that the passage time is reduced as the speed of the queued vehicles increase. This advanced topic was likely investigated while working as an engineer. As a result, the passage time discussion was in the context of the engineer's engineering experience.

Practicing Engineer: Passage time is the amount of time after the last detection that is held green for the vehicle to get through. So passage and min-gap are intimately tied to each other, kind of the same thing. What you do is you ***generally start with a larger passage time until the vehicles get moving and then you reduce it. There's a time before***

reduction and a time to reduce that determine how you get down to your minimum gap and your minimum gap is in play when you have free-flowing traffic

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Semi-Actuated Signals

Semi-actuated signals are traffic signals that rest in green on the main movements and contain detectors on the minor movements. When a vehicle is detected on a minor approach, the signal counts down a timer to end the green indication on the main approach and gives a green indication for the minor approach(s).

This expert student displayed a misconception by indicating that detectors are placed on the major street for a semi-actuated signal.

Interviewer: So where should the detector be?

Expert Student: You mean where should it be? Or I think if semi-actuated should consider this approach and also this approach.

Interviewer: So you will have detector on main street.

*Expert Student: **Main street**, yes.*

This practicing engineer displayed a misconception by indicating that a semi-actuated signal has a fixed cycle length.

*Practicing Engineer: Well okay **a semi-actuated means that you have a fixed cycle length** and you basically fix a certain window on the major street and leave that green during a particular time in the cycle and then you allow the side streets to be served or left turns to be served as the traffic demand is there.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

A correction in the semi-actuated signals misconception would be a benefit for traffic signal design. A correction would allow the semi-actuated signals to operate more efficiently. Furthermore, semi-actuated signals might become a more viable option if they are understood correctly.

None of the expert students discussed a context quotation for semi-actuated signals. This practicing engineer explained how semi-actuated signals operated, and knew specific terminology. The engineer most likely has designed semi-actuated signals, thus the explanation was in the context of the engineer's engineering experience.

> *Practicing Engineer: Semi-actuated is going to require the* ***movements that don't have detection to be on recall****. And they won't have-- ________ that don't have any detections on them won't have any dilemma zone on the detection. Semi-actuated will, you know, for those movements,* ***typically for the left turns and minor street approaches will have detection and then will fall back to the main line****.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Vehicle Volume

Vehicle volumes are the amount of vehicles that travel on a specific approach for a certain amount of time. The vehicle volume data is key to the justification and operations of traffic signals.

This novice student displayed a misconception by indicating that a guess is made for the traffic volumes and the traffic signal is adjusted in the field, if the volume data is not available.

Interviewer: What do you think would happen if no traffic data was available?

Novice Student: You'd probably just have ***to kind of guess, and then adjust it later on based on how the signal is performing****, and how much traffic is backing up in each direction.*

This expert student displayed a misconception by indicating that traffic volumes are not required if other warrants are met to justify the traffic signal.

Expert Student: ***Depends if you have other data that would help like continue through the warrant analysis without the traffic data****, like the crash history or the pedestrians, or proximity to a railroad for warrant nine [ph?] because the volume data is probably four of the nine warrants or so and then there's another five that could be maybe looked at without volume data.*

This practicing engineer displayed a misconception by indicating that traffic volumes should only be collected from Tuesday through Thursday.

Practicing Engineer: And so we'll typically run a three hour Tuesday through Thursday 24 hour period; or a 36 I guess. No, at least a 36 hour within those three days, because ***we don't count on Mondays, we don't count on Friday, we don't count on the weekends. It's just so it's Tuesday through Thursday****.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

If the vehicle volumes misconception was fixed, then traffic signal justifications may be more accurate and the amount of green time given to each of the approaches of the traffic signal may be more efficient as well.

This novice student discussed that signals may exist at non-busy intersections because the volumes have decreased since it was installed. The student may have observed a decrease in traffic volumes, such as a large store that went out of business that caused a traffic signal to become less busy. As a result, this novice student's explanation on vehicle volumes was in the context of the novice student's driving experience.

Interviewer: Okay. Cool. Are there situations where non-busy intersections may still have a traffic signal?

Novice Student: Yeah, like I said before you could have at a main highway intersecting with a less populated road or ***if traffic starts to decrease in an area when the light was put in when there was heavy traffic****.*

This expert student explained that the 30th highest peak hour volume should be considered instead of the absolute highest volume in a year. This expert student understands the balance of efficiency and cost, and was likely studied in the student's coursework. As a result, this expert student explained vehicle volumes in the context of advanced coursework.

Interviewer: What traffic volumes should be considered when faced with a decision of installing a new traffic signal?

Expert Student: ***Well, you're probably not going to be considering the highest day of the year. I think a pretty common standard is the 30th highest peak hour volume****, and that basically gives us a* ***good balance of performing efficiently most of the time without overbuilding the road*** *for those very rare football game events in Corvallis.*

These practicing engineers explained that if a road does not exist yet, then regional models and projections are used to determine the traffic volumes. These engineers likely had to project traffic volumes for a road that has not been built yet. Thus, the engineers discussed vehicle volumes in the context of their engineering experience.

Interviewer: What do you do if no traffic volumes are available?

Practicing Engineer 701: ***For intersections that don't currently exist, I mean, you can't go out and count it because it's a new road. And then you're relying on the regional model****. You need to do some sort of-- which is basically a scientific wild guess.*

Practicing Engineer 700: An iteration of sorts.

Practicing Engineer 701: Yeah. And you try to see whether it's actually going to warrant signals, you know.

Practicing Engineer 700: ***Projections****, yeah.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

All-Red Time

The all-red time is a factor of safety in which all of the signal heads display a solid red indication. The purpose is to make sure the intersection is clear of conflicting traffic before the next phase gets to move through the intersection.

This novice student displayed a misconception by not understanding that all the signal heads can be red at the same time as part of normal traffic signal operations.

Interviewer: Do intersections ever show a red light on every approach, and if they do, then why would they do that?

Novice Student: On every approach?

Interviewer: Correct. So every signal head out there; is there a time where there is no green light, that they're all red?

Novice Student: That ***probably just means four-way stop or you have to stop****. That's my understanding. That's what I perceive it as.*

This expert student displayed a misconception by indicating that the duration of the all-red time depends on the traffic volume.

Interviewer: Considering that, let's say I am putting half a second of all-red time for all intersections in the city. Would that be justified? Or do you think that that should be changed for some intersections? I mean, my question is precisely how would you determine that.

Expert Student: I mean, I think you have to look at it by an intersection-by-intersection basis. Because some intersections-- ***say they have low volume of traffic-- aren't going to need to have that****. But I mean, certainly some of them will. So I think you just have to look at the need for intersections, if you can model the rate at which drivers go through yellow lights or not.*

Interviewer: And so the duration of all-red, when you think about that, your volume is affecting that, right?

Expert Student: Yeah.

This practicing engineer displayed a misconception by indicating that the all-red time can be shortened for a coordinated traffic signal.

Practicing Engineer: ***In a coordinated system I usually have more incentive to keep the loss time at a minimum*** *and so sometimes even if our calculation shows that maybe a 2* *second all red would be best,* ***we may shorten that****, just for the purpose of trying to get the signal moving around quicker.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

The correction of the all-red time misconception would result in safer traffic signals. The all-red time is a safety factor, so the improved understanding would improve the safety of signalized intersections.

This novice student discussed an all-pedestrian phase, in which all of the signal heads would be red. Since the novice student does not know if their response is actually performed in the real world, the context in which the all-red time was discussed is inconclusive.

> *Novice Student: That might not be all red, but I think if there is an all-red time,* ***if there's a lot of pedestrian traffic in all directions, they might introduce an all-red time to let all the pedestrians go at once****, just to get them out of the way. I don't know.* ***They might not do that.*** *It's just something they might do in more pedestrian heavy areas, like downtown.*

This expert student explained that the all-red time is optional. The expert student likely studied the all-red time in the student's coursework, thus the all-red time was discussed in the context of the advanced coursework.

> *Expert Student: You do not have to. I mean, there's a-- I think it's* ***recommended that you have a little bit of it, but you don't have to have it****.*

This practicing engineer discussed that a high all-red time may encourage red light running. The engineer may have seen the affects of a long all-red time in the field. Thus, the engineer discussed the all-red time in the context of engineering experience.

Practicing Engineer: It's basically to give a little safety cushion for the side traffic, so that people that run the red lights and what not can get a little bit of added safety there that the whole signals red. Generally, you don't want to get that too high. ***If you have an all red time too high, people will start catching on and expect all signals to be like that and it may encourage more red light running****. So there should be-- I think we don't really put between one and two seconds on that so.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

Effective Green Time

The effective green time can be found be adding the green time of an approach, the yellow time, and the all-red time and subtracting the start-up lost time (Effective Green Time = Green Time + Yellow Time + All-red Time – Start-up lost time). The purpose is to know how long vehicles will really have to proceed through the intersection.

This expert student displayed a misconception by indicating that the effective green time is the total green time minus the start-up lost time.

Expert Student: Your effective green time is your total green time with any kind of lost time removed. And so your lost time is going to be the headway between vehicles and then the startup lost time as well. So when you first display the green indication, it takes some time for the first driver to react and so that time is essentially wasted. And then it takes some time for each other vehicle to react and eventually have that lost time. I guess, though, that's-- no. Effective green time is just based on the startup lost time I think. And that obviously would be for each phase, every time you display a green indication there's *going to be some start up lost time there. So depending on your number of phases will determine, you know, if you've got two seconds of startup lost time, every phase, in your four phases you'll have eight seconds of start lost time. And then you'd have to figure out how long your cycle length is and then figure out how many phases you have in that cycle length and then you'll have that much-- you know,* ***your green time minus all of the startup lost time for each phase. That will be your effective green time for that cycle****.*

This practicing engineer displayed a misconception by indicating that the effective green time is the green time.

Practicing Engineer: Effective green time, I think, is the amount of time that is actually available to a vehicle or to an approach. So, I think I'm thinking about that right. Yes, so the amount of time that, you know, a northbound car has green is their effective green time. Is that right?

Interviewer: I'm not allowed to say. <laughs>

800: It seemed like there's an adjustment factor in there somewhere, but essentially it is, yes, ***how much an actual approach has a green time****.*

As a result, these quotations were representative of the misconceptions discussed by each of the cohorts.

The correction of the effective green time misconception would provide a more accurate representation on how long vehicles will practically have to move through the intersection. This correction may improve traffic signal operations in some cases.

This expert student explained that the effective green time would be greater for a coordinated signal because the start-up lost time is eliminated. This student likely studied the effective green time and coordinated signals in the student's coursework. Thus, the expert student discussed the effective green time in the context of advanced coursework.

Expert Student: Yeah. So, because you're assuming that you've got vehicles that are traveling through multiple signals now, and they're timed accordingly, ***you're going to have more effective green time because you eliminate that startup delay****. So you gain a few seconds at the beginning, so you've got-- I mean, your effective green time is better because you can lower the cycle length.*

This practicing engineer discussed that if a traffic signal maxes out a lot, then it is important to investigate why the signal keeps maxing out. The engineer likely encountered a scenario where a signal maxed out a lot in the field. Thus, the practicing engineer discussed the effective green time in the context of the engineer's engineering experience.

Interviewer: Or the effective green time, just as the big picture.

Practicing Engineer: Well that's-- really it's your efficiency, if you're getting your movements through in that allotted green time, then you're running pretty efficient. If you've got a lot of-- it depends on if you're running fully actuated-- I don't know how to say this. The main thing is to run as efficient as possible. If you've got-- if you're gapping out or maxing out, you know, if you're gapping out frequently, then you're probably not using your time wisely. ***If you're maxing out, then you probably need to look at why you're not getting everybody through****. I don't know if I've answered your question.*

As a result, these quotations were representative of the context quotations discussed by each of the cohorts.

DISCUSSION

The misconception prevalence and the context of the concepts were used to compare the novice students, expert students, and practicing engineers in the field of traffic signal engineering. The misconception prevalence results showed that the concepts could be separated into four misconception trends. Interestingly enough, most of the concepts did not follow the misconception trend hypothesized by the researchers. In fact, only three concepts followed a trend hypothesized by the researchers. This section provides an explanation for the misconception trends that did not exhibit a trend hypothesized by the researchers.

Expert Students as the High Misconception Trend

The 'Expert Students as the High Misconception Trend' contained six concepts that did not follow a misconception trend hypothesized by the researchers. This trend was not hypothesized, because the expert students displayed the highest misconception prevalence. Thus, the trend was examined in order to find an explanation for the unexpected trend.

The relatively low misconception prevalence for the novice students may be a reflection of the novice students' shallow understanding of the six concepts. Thus, the limited background on traffic signal engineering prevented the novice students from discussing more advanced knowledge, which resulted in discussing fewer misconceptions. For example, this misconception quotation shows a very limited understanding that this novice student had with vehicle detection.

Interviewer: What does a signal do when it detects a vehicle?

Novice Student: It probably ***puts it in line****, or whatever, within the whole cycle of signal A, B and C, or whatever. I don't know. I'm not explaining it very well right now.*

This novice student mentioned that a vehicle gets in line to be served once it is detected by the signal. This misconception indicates that the novice student does not understand the basics of phase order, such as the ring-and-barrier diagram. As a result, the relatively low misconception prevalence for the novice students is likely a reflection of the novice students' shallow understanding of the six concepts for this trend.

The high misconception prevalence for the expert students may be a reflection of the expert students' awareness to advanced topics of the six concepts. The expert students were likely introduced to advanced knowledge through their advanced coursework, but they have not had the professional experience of practicing the concepts in the real world. For example, this expert student misconception quotation showed that the student was aware of more advanced uses for vehicle detection.

> *Expert Student: I don't know; I guess it would be the advanced detector would detect a vehicle that was too close to the intersection to stop and would allow them to proceed through the intersection once the stop detector, you know, activated the-- so, start at the beginning, the car comes to a stop detector; starts the stopping process, but the* ***advanced detector would detect a vehicle that was too close to the intersection to stop and would lengthen the yellow phase to let them proceed****; I think; I don't know that. That's my guess.*

This expert student was aware of the existence of advanced detectors, and that advanced detectors are used to influence the signal indication to allow a vehicle to safely pass through the intersection if the vehicle is too close to stop. However, the student does not understand the correct process for the advanced detector to assist vehicles in the dilemma zone, and was unsure about the answer. Thus, the expert student was aware of the use of vehicle detection and the dilemma zone, but does not have a complete understanding of the topic. As a result, the high misconception prevalence for the expert students may be a reflection of the students' awareness to advanced topics of the six concepts.

The practicing engineers had a relatively low misconception prevalence for the six concepts, which was expected by the researchers. The low misconception prevalence was likely a reflection of the knowledge gained from engineering practice.

In conclusion, the high misconception prevalence of the expert students is likely a result of the expert students' awareness to advanced topics, but they have not had the engineering experience to completely comprehend the topics. The novice students having a lower misconception prevalence does not mean that the novice students understand the concepts better than the expert students, because the novice students have not been exposed to the more advanced topics for these concepts. Furthermore, the expert students displayed the same or greater context prevalence than the novice students, which also suggests that expert students have a wider range of knowledge for the six concepts. To sum up, the high misconception prevalence for expert students is a result of the students' awareness to advanced knowledge for the concepts in the 'Expert Students as the High Misconception Trend'.

The Reverse Hypothesized Trend

The 'Reverse Hypothesized Trend' contained four concepts that did not follow a misconception trend hypothesized by the researchers. In general, the concepts presented in this trend were considered too technically advanced for the novice students, thus the novice students were left out of the analysis. This trend was not hypothesized, because the practicing engineers generally displayed the highest misconception prevalence. Thus, the trend was examined in order to find an explanation for the unexpected trend.

The expert students had relatively low misconception prevalence for the four concepts in this trend. The reasoning could be these four concepts (minimum green time, passage time, semi-actuated signals, and vehicle volume) are more advanced topics and the students likely were taught the correct way to understand these concepts in their advanced coursework.

The practicing engineers had relatively high misconception prevalence for the four concepts in this trend. These concepts often have a standard in which agencies use these concepts. As a result, the practicing engineers may have gotten use to applying the concepts based on agency standards and not necessarily understanding the application for the concepts. This context quotation shows that standards are used in engineering practice.

> *Practicing engineer: Depending on the speed and depending on the volume is what we set our maximum green times on and* ***our mins are typically 5 seconds*** *unless there's like a hill or a lot of trucks.*

This engineer explained that a standard minimum green time is typically used in practice. As a result, engineers may become accustom to applying standards and may not fully understand the reasoning behind the standards.

In conclusion, the high misconception prevalence for practicing engineers in the 'Reverse Hypothesized Trend' are likely a result of engineers that become accustom to using standards and may not fully understand the reasoning behind the standards. The lack of a full understanding may lead to misconceptions. Thus, the result of high misconception prevalence is likely a result of how the engineer applies the four concepts in practice.

The Equal Levels of Misconceptions Trend

The 'Equal Levels of Misconceptions Trend' contained two concepts that did not follow a misconception trend hypothesized by the researchers. This trend was not hypothesized, because the cohorts all displayed a similar level of misconception prevalence. Thus, the trend was examined in order to find an explanation for the unexpected trend.

All the cohorts had high misconception prevalence for the two concepts in this trend, including the effective green time that had the highest misconception prevalence out of the 15 concepts investigated. Furthermore, the context prevalence was relatively low for both concepts when compared to other concepts in the same cohort. The following misconception quotations further demonstrate that the all-red time was a difficult concept. For example, this novice student did not understand that an all-red time is used in normal traffic signal operations. The novice student's discussion suggested that the student was confused that traffic signals could be red on every approach, and then concluded that the application of all-red time is used for four-way stops.

> *Interviewer: Do intersections ever show a red light on every approach, and if they do, then why would they do that?*
>
> *Novice Student:* ***On every approach?***
>
> *Interviewer: Correct. So every signal head out there; is there a time where there is no green light, that they're all red?*
>
> *Novice Student: That* ***probably just means four-way stop or you have to stop****. That's my understanding. That's what I perceive it as.*

This expert student, who thought the all-red time depends on the traffic volume, displayed another example that the all-red time was a difficult concept. This quotation showed that the student does not understand that the all-red time is a safety factor, regardless of the traffic volumes.

> *Interviewer: Considering that, let's say I am putting half a second of all-red time for all intersections in the city. Would that be justified? Or do you think that that should be changed for some intersections? I mean, my question is precisely how would you determine that.*
>
> *Expert Student: I mean, I think you have to look at it by an intersection-by-intersection basis. Because some intersections--* ***say they have low volume of traffic-- aren't going to need to have that****. But I mean, certainly some of them will. So I think you just have to look at the need for intersections, if you can model the rate at which drivers go through yellow lights or not.*
>
> *Interviewer: And so the duration of all-red, when you think about that, your volume is affecting that, right?*
>
> *Expert Student: Yeah.*

This practicing engineer showed yet another example that the all-red time was a difficult concept, by indicating that the all-red time can be shortened for a coordinated traffic signal. Thus, the engineer does not understand that the all-red time is a factor of safety, and this factor of safety should not change based on if the traffic signal is isolated or coordinated with other traffic signals.

> *Practicing Engineer:* ***In a coordinated system I usually have more incentive to keep the loss time at a minimum*** *and so sometimes even if our calculation shows that maybe a 2 second all red would be best,* ***we may shorten that****, just for the purpose of trying to get the signal moving around quicker.*

As a result, the all-red time was a difficult concept for all three cohorts.

As a result, the two concepts in the 'Equal Levels of Misconceptions Trend' were difficult concepts for all three cohorts. All the cohorts had high misconception prevalence, relatively low context prevalence, and the example misconception quotations further showed that the concepts were difficult. The high level of difficulty resulted in all three cohorts displaying similar misconception prevalence, because the three cohorts all had a difficult time completely understanding the concepts in the 'Equal Levels of Misconceptions Trend.'

Limitations of Study

This study contained several limitations. One limitation was having two people code the interviews. Although great lengths were taken to ensure consistency, people would have different interpretations of the interview transcriptions and would lead to some minor inconsistencies of the coding of the interviews. However, the researchers developed a process to ensure comparable results.

Another study limitation was the subjective natures that are associated with qualitative analyses. Several of the quotations in the interviews could have been labeled as several different codes. The study compensated for this subjective piece of the coding by coding everything the same way. Another limitation with the data analysis was the strength of the codes associated with the quotations. Some of the codes assigned to the quotations were obvious misconceptions or contexts so the codes were placed with strong confidence. And some codes were placed on quotations that were more susceptible for the researcher's interpretation. Allowing the two researchers to discuss questionable quotations lowered this limitation. However, the different strengths of the codes assigned to the quotations prohibited the use of statistical tests (Independent Sample T-Tests, ANOVA, etc.) to determine statistical differences in the data set.

Another limitation of the study was that the data collection occurred in the Pacific Northwest, and it is unknown if the results are generalizable for the entire country. However, the data collection occurred at two universities and across two metropolitan areas to minimize this effect.

Another limitation of the study included the novice student protocol. The novice students would not understand some of the technical terms that were asked on the protocol used for the expert students and the practicing engineers. As a result, the novice students received a different protocol without the technical terms. Although both protocols were designed from the same concepts, a limitation to the study is that there were two different interview protocols involved.

CONCLUSION

In conclusion, the results of the misconception prevalence and the context of the concepts were used to compare the knowledge of traffic signal engineering between the novice students, expert students, and practicing engineers. The misconception prevalence of the concepts were found to fall into four misconception trends, including the 'Hypothesized Trend,' 'Expert Students as the High Misconception Trend,' 'Reverse Hypothesized Trend,' and 'Equal Levels of Misconceptions Trend.' The investigation of the misconception prevalence revealed that most of the concepts did not follow the trend hypothesized by the researchers. Furthermore, the results of the misconception prevalence also revealed frequent misconceptions across the three cohorts. The investigation on the context prevalence revealed that the three cohorts generally followed the trend hypothesized by the researchers. Furthermore, the novice students generally discussed the concepts in the context of their driving experience, the expert students discussed the concepts in the context of their advanced coursework, and the practicing engineers discussed the concepts in the context of their engineering experience. As a result, the three cohorts discussed the concepts in different contexts. The practicing engineers discussed the concepts in the context of their engineering experience, which is the most applicable context for the field of engineering between the three cohorts. Thus, the results of this study confirm the hypothesis that the engineers would have the most applicable context for the traffic signal concepts between the three cohorts.

Consequently, engineering curriculums should present concepts in the context of how engineers use the concepts in the real world to foster students to think about the concepts in a similar fashion as engineers. This would result in engineering students who are better prepared for the engineering workforce.

FUTURE STUDIES

Studies In Different Geographical Regions

Future studies should investigate the same research questions as this study, but collect data in geographic regions outside of the Pacific Northwest. The reasoning behind repeating this study's investigation into different geographical regions is because it is unknown if the results would be generalizable for the entire country.

Comparing knowledge of traffic signal engineering between novice students, expert students, and practicing engineers from different parts of the country would help ensure that engineering curriculums are addressing the correct misconceptions and context of concepts for that particular region. For instance, the concepts with the highest misconception prevalence may differ from the Pacific Northwest and another region of the country. Thus, instructors from different regions may want to validate that they are addressing the proper misconceptions in the engineering curriculum. Furthermore, it would be beneficial to determine the context in which the traffic signal engineering concepts are discussed in different regions of the United States. This information could enable instructors to prepare curriculum in a way that presents concepts in the same context that the engineers in the region discussed the concepts.

As a result, the misconception prevalence and the context of the concepts may differ across geographical regions. Thus, future studies from different geographical regions could help improve engineering curriculums in the different regions, by considering the misconception prevalence and the context of the concepts.

Studies In Different Engineering Fields

Future studies should compare misconception prevalence and context of concepts in fields beyond traffic signal engineering. The same principles as this study could be applied to additional topics of transportation engineering, civil engineering, and other branches of engineering.

A study performed in other topics of transportation engineering may lead into interesting comparisons with the study conducted in this paper. For example, a study that compares students' and engineers' knowledge in traffic performance may identify misconceptions that overlap with the study presented in this paper. The overlapped misconceptions prevalence could be compared to see if the prevalence differed when the study was focused on traffic signal engineering versus traffic performance.

In addition, studies that include the comparison of students' and engineers' knowledge in a different civil engineering field may also lead to interesting comparisons with the study conducted in this paper. If similar misconception trends were identified for the two studies, then it would be interesting to compare the explanations for the misconception trends. This comparison of different civil engineering fields may lead to further insight in the overall explanations for the misconception trends.

Furthermore, a similar study conducted in a different branch of engineering would also lead to interesting results. It would be interesting to determine if the same misconception trends develop for different engineering fields. It would also be interesting to determine if the context of the explanation of concepts are the same across different engineering fields. This knowledge of comparing results from different engineering fields may lead to broader conclusions about misconception prevalence and context of engineering concepts.

References

Brown, J. S., Collins, A., Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18(1)*, 32-42.

Brown, S., Street, D., Barker, F. (2013). Motivational factors influencing in-class peer tutors in engineering: a functional approach. *International Journal of Engineering Education, Vol. 29, No. 1*, 1–13.

Chi, M. T. H., Feltovich, P. J., Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5*, 121-152.

Chi, M. T. H. (2006). The Cambridge Handbook of Expertise and Expert Performance. K. A. Ericsson, N. Charness, P. J. Feltovich, R. R. Hoffman (Eds.). *Laboratory Methods for Assessing Experts' and Novices' Knowledge*. (pp. 167-184). Cambridge University Press.

Chi, M. T. H. (2011). Theoretical perspectives, methodological approaches, and trends in the study of expertise. *Springer Science+Business Media, LLC*, 17-39.

ciHUB. (2011). ciHUB.org website. Retrieved from http://cihub.org/

Cooke, N. J. (1994). Varieties of knowledge elicitation techniques. *International Journal of Human-Computer Studies, 41*, 801–849.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. *American Association of Physics Teachers, 66 (1)*, 64-74.

Hoffman, R. R., Lintern, G. (2006). The Cambridge Handbook of Expertise and Expert Performance. K. A. Ericsson, N. Charness, P. J. Feltovich, R. R. Hoffman (Eds.). *Eliciting and Representing the Knowledge of Experts*. (pp. 203-222). Cambridge University Press.

Krause, S., Waters, C. (2012). Uncovering and repairing crystal structure misconceptions in an introductory materials engineering class. *IEEE*.

Lave, J., Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. (S. Chaiklin, J. Lave, Eds.). Cambridge University Press.

Mayer, R. E. (2009) Development of Professional Expertise. Ericsson, K. (Eds.), *Advances in Specifying What Is to Be Learned: Reflections on the Themes in Chapters 6-8* (pp. 203-211). Cambridge University Press.

Muhr, T., CEO, Atlas.ti, 1993-2013, Berlin.

Richardson, J., Steif, P., Morgan, J., and Dantzler, J. (2003). Development of a concept inventory for strength of materials. *33rd ASEE/IEEE Frontiers in Education Conference*, *Session T3D*, 29-33.

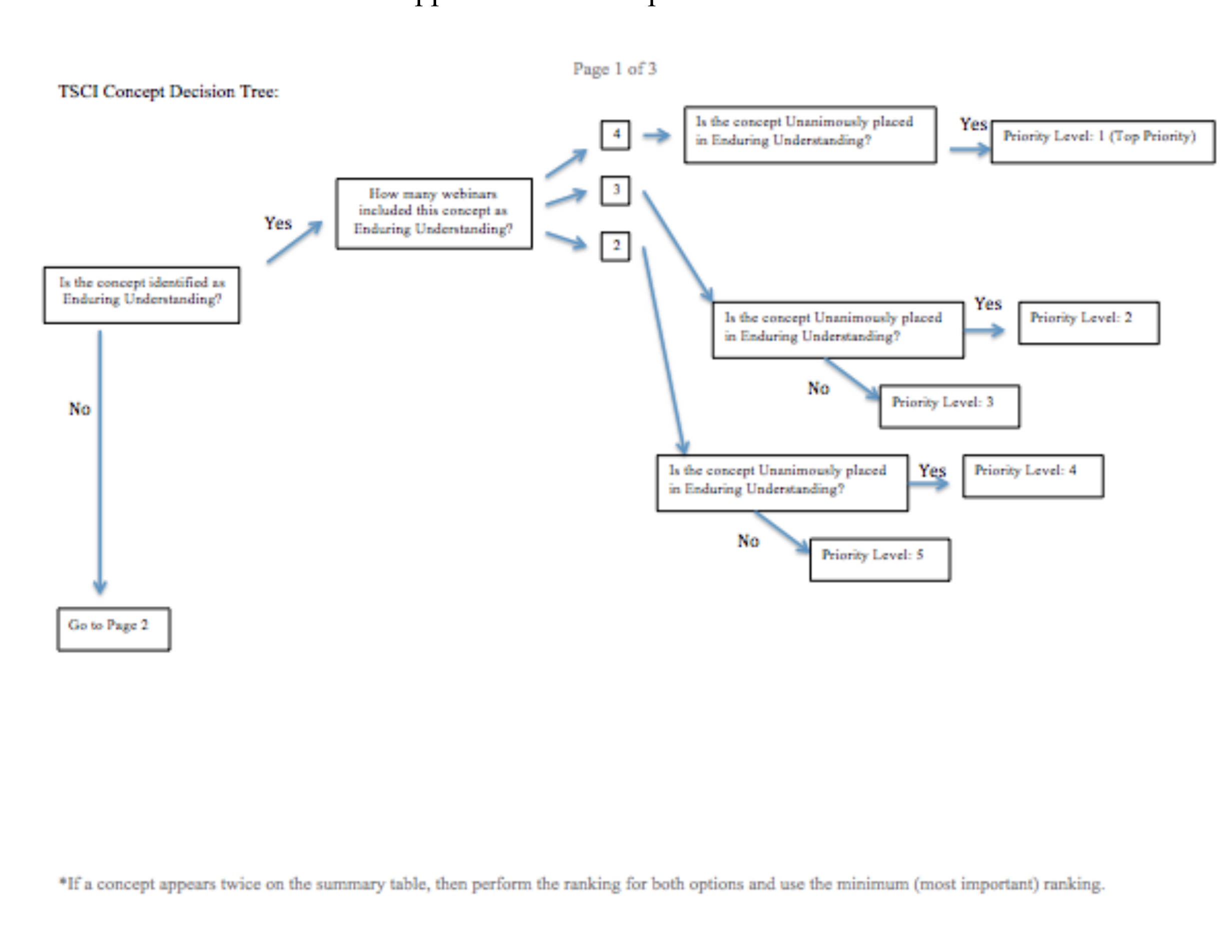
Simon, D. P., Simon, H. A. (1978). Children's Thinking: What Develops?. R. S. Siegler (Ed.). *Individual Differences in Solving Physics Problems*. (pp. 325–348). Lawrence Erlbaum Associates, Inc., Publishers. Hillsdale, New Jersey.

Van Merriënboer, J. J. G., Boot, E. W. (2009) Development of Professional Expertise. Ericsson, K. (Eds.), *Research on Past and Current Training in Professional Domains: The Emerging Need for a Paradigm Shift* (pp. 131-156). Cambridge University Press.

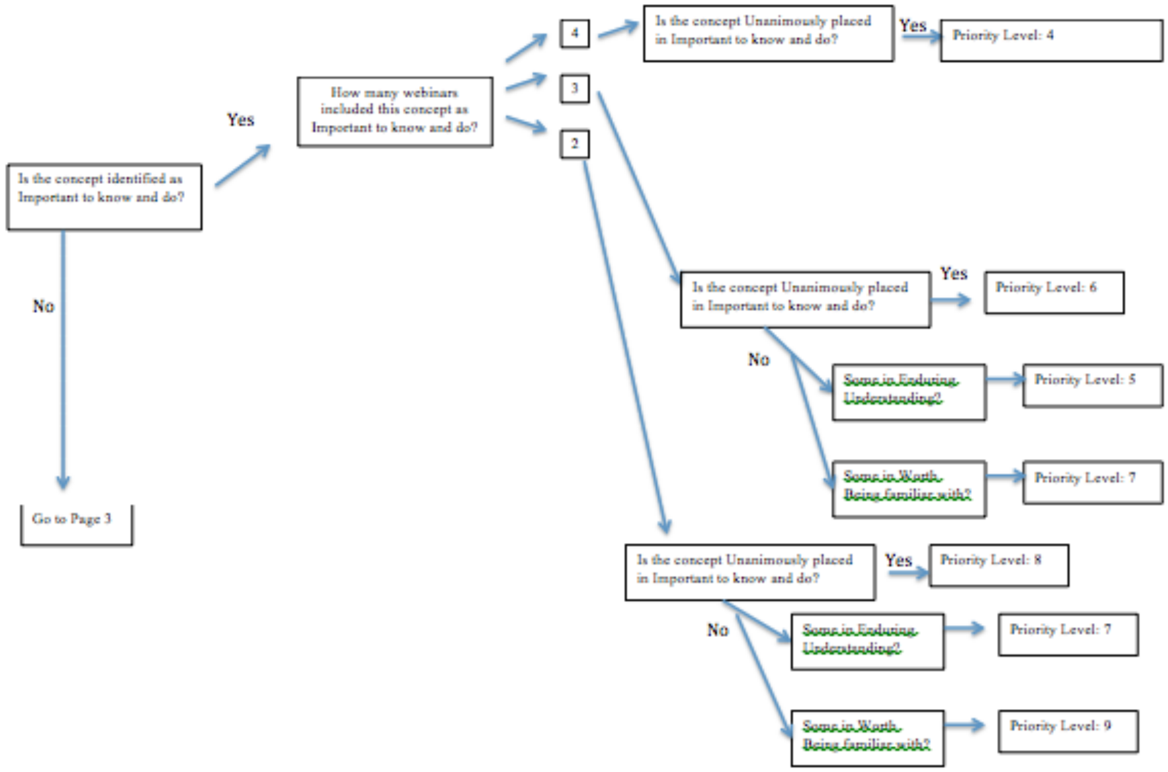
VanLehn, K., Van De Sande, B. (2009) Development of Professional Expertise. Ericsson, K. (Eds.), *Acquiring Conceptual Expertise from Modeling: The Case of Elementary Physics* (pp. 356-378). Cambridge University Press.

Wineburg, S. S. (1991). Historical problem solving: a study of the cognitive processes used in the evaluation of documentary and pictorial evidence. *Journal of Educational Psychology, 83*, 73–87.

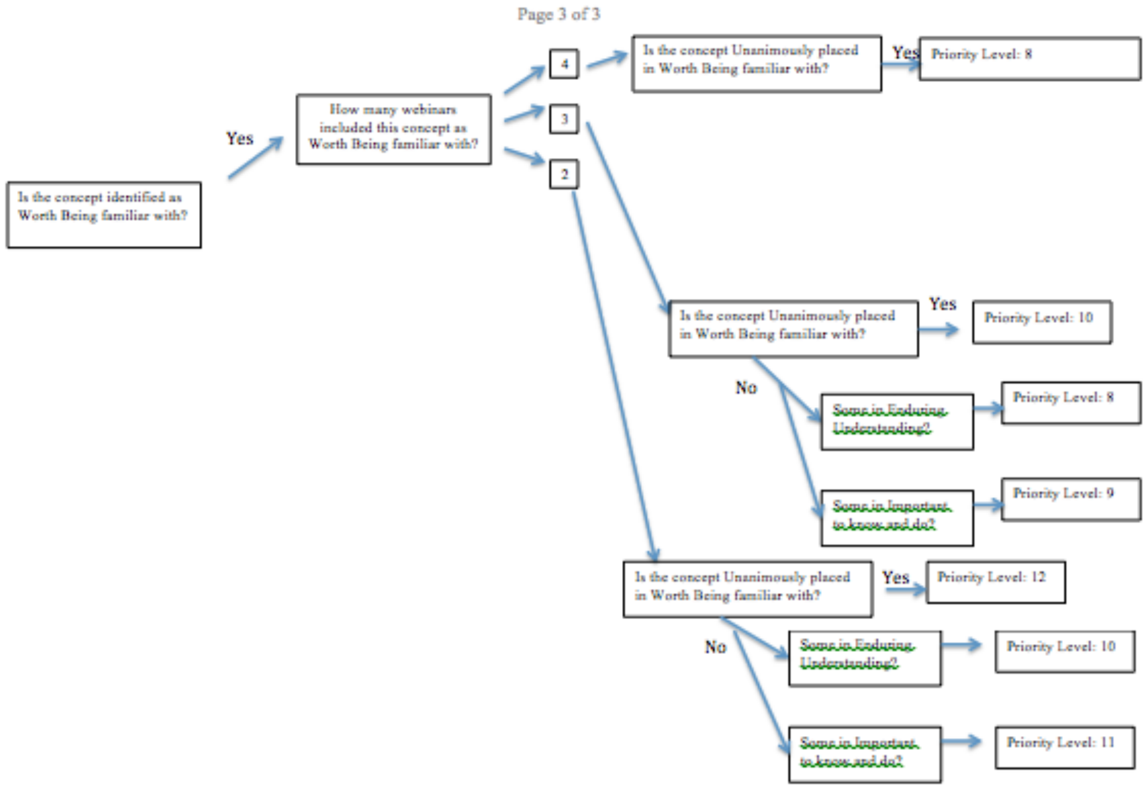
Appendix A: Concept Decision Tree



Page 2 of 3



*If a concept appears twice on the summary table, then perform the ranking for both options and use the minimum (most important) ranking.



*If a concept appears twice on the summary table, then perform the ranking for both options and use the minimum (most important) ranking.

Appendix B: Prioritized Concepts from Expert Webinars

Prioritized Concepts from Expert Webinars

Concept:	Priority:
Traffic signal warrants	1
Signal Timing (cycle length, effective green time, phase splits, G/Y/AR)	1
Traffic signal phasing (Phase & Ring Barrier Diagrams)	2
Queuing Theory	2
Timing Parameters (Min / Max Green, PT, etc.)	2
Time Space Diagrams	2
Offsets	2
Traffic Progression	2
Flow Rates: Saturation Flow Rate, Flow Rates (Arrival, Departure)	4
Capacity	4
Traffic Directionality	4
Splits	4
Common Cycle Lengths	4
Bandwidth	4
Traffic Management Centers	4
Traffic Networks (Types: downtown grid, network of arterials)	4
Vehicle Detections (placement, length)	5
Multi-model (Pedestrians, Bikes, Pedestrian Actuation)	6
Driver Behavior (Reaction Time)	8
Phase Termination	8
Signal Preemption (Emergency Vehicles, Transit, Trains)	10
Pedestrian Accommodations (Pedestrian push buttons, Bike/Ped Signals)	10
Performance Measures	12
SCOOTS/SCATS/ITS	12

Appendix C: Practicing Engineers and Expert Students Interview Protocol

Concept:	Interview Question:	Probing Questions:
Introduction	Ask how the participant is doing. Introduce myself. Introduce the study and summarize how the interview questions were formed. State the purpose of the interview. Tell the participant that some questions may seem redundant. This interview is not a quiz. Ask if it is okay to audio record. Explain to the participant that their answers are **confidential**. Ask participate to say name, title, company name. "How many years of experience do you have in traffic signal design?" "There are no right or wrong answers, we just want to know your ways of thinking about these concepts and how you use them in practice."	
Traffic Signal Justifications. (Concept: Traffic signal warrants)	What factors contribute to the decision making process of installing a new traffic signal? What kind of crash data is useful for the decision of installing a new traffic signal? What pedestrian data is useful for making the decision of installing a new traffic signal? How would you use gap data for the decision of installing a new traffic signal? What traffic volumes should be considered when faced with a decision of installing a new traffic signal? What do you do if no traffic volumes are available? What assumptions may be necessary for the decision of installing a new	

	traffic signal? How is the speed of an approach determined? Where would you find documentation for traffic signal warrants?	
Signal Timing (Concept: Signal Timing (cycle length, effective green time, phase splits, G/Y/AR))	What are the different types of traffic signal control? What is the difference between the operation of a semi-actuated and a fully actuated signal control? What is the difference between the operation of a pre-timed and a fully actuated signal control? What elements make up the signal timing for an isolated intersection? What signal-timing parameters would be used to coordinate signals? How is the cycle length determined for an intersection in a coordinated corridor? What differences, if any, exist in determining the cycle length between	What factors contribute to the cycle length for an isolated intersection? What is the purpose of effective green time for an isolated intersection? What is a phase split for an isolated intersection? What is the purpose of the Yellow time for an isolated intersection? What is the purpose of the All Red Time for an isolated intersection? How are these signal-timing parameters used or considered when coordinating signals?

	an isolated intersection and an intersection in a coordinated corridor? How does the determination of the effective green time differ between an isolated intersection and an intersection in a coordinated corridor? How does the determination of the Yellow time differ between an isolated intersection and an intersection in a coordinated corridor? How does the determination of the All Red time differ between an isolated intersection and an intersection in a coordinated corridor?	
Traffic signal phasing (Concept: Traffic signal phasing (Phase & Ring Barrier Diagrams))	What is a phase for a signalized intersection? What information appears on a Ring Barrier Diagram? How is a phase terminated in a pre-timed isolated signal? How is a phase terminated in an actuated isolated signal? How are phases terminated at an isolated signal versus a *coordinated* signal? How are detectors used at an actuated signal? How does detector length affect phase termination?	Can you explain why this method was chosen? Can you explain why this method was chosen? What are the advantages & disadvantages of actuated control verses pre-timed control?

	What is the difference between an advanced detector and a stop-line detector?	When would you need an advanced detector?
Timing Parameters (Concept: Timing Parameters (Min / Max Green, PT, etc.))	What are the basic timing parameters for an isolated actuated traffic signal?	What is the purpose for the minimum green time? What is the purpose for the maximum green time? What is the purpose for the passage time?
Conclusion	Are there any other concepts you feel are fundamentally important for students to learn about traffic signal design? "Thank You for your time" **Stop Recorder** Would you like to chat about any of these questions? If yes: "The "answers" depend upon context, situation, and per person; but here is what I think…"	

Appendix D: Novice Students Interview Protocol

Concept:	Drivers (Experience) Prospective:	Designer Prospective:
Introduction	Ask how the participant is doing. Introduce myself. State the purpose of the interview. Tell the participant that some questions may seem redundant. This interview is not a quiz. Ask if it is okay to audio record. Explain to the participant that their answers are **confidential**. Ask participate to say name "There are no right or wrong answers, we just want to know your ways of thinking about these concepts."	
Traffic Signal Justifications. (Concept: Traffic signal warrants)	What are the reasons to place a signal at an intersection? Why do you think traffic signals are not located at every intersection? Do you think traffic signals improve the safety of an intersection? Please Explain. Do you think the number of pedestrians around the intersection influence the placement of traffic signals? Why or why not? Imagine you are waiting to turn onto a major roadway. Do you think the gaps between vehicles on the major roadway would be important for the decision of installing a new traffic signal? Please explain? Are traffic signals usually placed at busy intersections? How would you define a "busy intersection?" Are there situations where "non-busy" intersections have a traffic signal?	Do you think you would need the speed of the vehicles approaching the intersection? If yes, then how is that speed found/estimated? How would you use this data to help design an intersection? Where could you find references or guidelines about the justifications of installing a signal at an intersection?

	What data is needed when deciding on the installation of a traffic signal? What do you think would happen if no traffic data is available?	
Signal Timing (Concept: Signal Timing (cycle length, effective green time, phase splits, G/Y/AR))	Imagine it is 2 in the morning, and you just arrived to a traffic signal with a red light. You are the only one at the intersection. Would all signals make you wait the same amount of time, or would some signals give you a green light sooner? Why do you think that is the case? Do all roads coming into an intersection receive the same amount of time for a green light? Or are the green durations different? Why are they different? Do all vehicles always get through on a green light? If not, then why do you think they did not get through? What is the purpose of the Yellow light for a signalized intersection? What should a driver do when they see a yellow light? What is your understanding of the law regarding driver response to a yellow light? Do intersections ever show a red light on every approach? Why do you think that is the case? Imagine you are driving downtown with signals on every block, and the signals work together to allow traffic to move through several signals. How	How should you divide the green times between the legs of an intersection if one road has a very high demand compared to the crossroad? What about an intersection with fairly similar demand on all approaches? How would you design the timing of a series of signals separated by close distances so they worked together? How do you think the cycle length (time between the beginnings of two successive greens on one approach) is determined for an intersection that is connected to other signals?

	do you think the signals allow traffic to move through multiple intersections? What are the benefits of these signals working together? How do connected signals work differently than non-connected signals? Connected signals are traffic signals that work together.	
Traffic signal phasing (Concept: Traffic signal phasing (Phase & Ring Barrier Diagrams))	How would you make sure that all the movements at an intersection eventually receive a green light? Have you noticed that when you go through an intersection other movements are stopped or shown a red light? Why is that? And, how do you make sure that all the lights are not green at the same time? Do you think the sequence of who gets to drive through the intersection is the same for all intersections? Or do some intersections have a different sequence? Have you ever stopped at a red light and the signal changed to green so fast, that it seemed liked the traffic signal knew you were there? If yes, then do you think the signal knew you were there? How do you think signals detect the presence of vehicles? What does a signal do when it detects a vehicle? If an intersection somehow knows a vehicle is present, how could it be more efficient than an intersection that	

	cannot sense vehicles?	
Timing Parameters (Concept: Timing Parameters (Min / Max Green, PT, etc.))	Have you ever seen a signal turn green and it turns red too quickly? Why do you think that happens?	Imagine there are too many cars on one street and the signal is always green to serve that demand. What problems may arise? How could these problems be solved? If there are no vehicles on one street and there are vehicles waiting on the cross

		street, how could the delay be lowered for those cars waiting on the cross street?
Conclusion	"Thank You for your time" **Stop Recorder** Would you like to chat about any of these questions? If yes: "The "answers" depend upon context, situation, and per person; but here is what I think…"	

Appendix E: Primary Codes List

Code List:

Actuated Characteristics	Collisions-Frequency
Coordinated Characteristics	Collisions-Type
Detection-Pedestrians	Collisions-Severity
Detection-Vehicles	Safety
Isolated Characteristics	Safety-Dilemma zone
Land Use	All-red
Land Use-Side Friction	Coordinated & isolated different process-cycle length, offset, progression
Pretimed Characteristics	Coordinated & isolated same process-Yellow or All Red or Effective Green
Signal Types	Cycle Length-Coordinated
Vehicle detection	Cycle Length-Isolated
Capacity	Effective Green Time
Cost	Gap out
Demand	Geometry/characteristics of Intersection
Demand-fluctuation	Green Time
Driver Behavior	Jurisdiction
Future Conditions-Traffic Planning	Left Turn Phasing
Multi Model	Lost Time
Peak Hour	Max Out
Pedestrian Counts	Max Time
Pedestrian Volume	Minimum Green Time
Vehicle Speed	Offset
Vehicular Volumes	Passage time
Engineering Judgment	Phase
Gaps- signal warrant	Preemption
References-Warrants-MUTCD	Red Time
Computer models	Ring Barrier Diagram
Field observations	Time Space Diagram
Performance Measures	Timing Plan
Progression	Yellow Time

Appendix F: Misconceptions and Concepts (Contexts) by the Quotes to Participation Ratio

	Cohorts (Quotes to Participation ratio)		
Misconceptions:	**Novice Students (n=17):**	**Expert Students (n=13):**	**Practicing Engineers (n=24):**
Approach Speed	0.76	0.36	0.17
Warrant References	0.65	0.23	0.00
All-Red Time	0.47	0.31	0.42
Cycle Length	0.47	0.85	0.21
Engineering Judgement	0.41	0.00	0.00
Coordinated Characteristics	0.35	0.54	0.29
Effective Green Time	N/A	0.85	0.88
Semi-Actuated	N/A	0.31	0.63
Yellow Time	0.18	0.38	0.25
Min Green Time	N/A	0.08	0.38
Actuated Characteristics	0.18	0.79	0.38
Passage Time	N/A	0.08	0.33
Vehicle Detection	0.18	0.92	0.21
Phase	0.18	0.69	0.29
Gaps	0.18	0.38	0.21
Vehicle Volume	0.12	0.38	0.29

	Cohorts (Quotes to Participation ratio)		
Concepts:	**Novice Students (n=17):**	**Expert Students (n=13):**	**Practicing Engineers (n=24):**
Engineering Judgment	0.59	0.08	0.42
Safety	0.47	0.00	0.38
Approach Speed	0.41	0.15	0.33
Cost	0.41	0.08	0.17
Timing Plan	0.35	0.00	0.00
Cycle Length	0.06	0.31	1.17
Detection	0.12	0.15	0.71
Actuated Characteristics	0.00	0.15	0.63
Pretimed Characteristics	0.06	0.15	0.58
Coordinated Characteristics	0.24	0.46	0.63
Vehicle Volumes	0.06	0.15	0.67
Future Conditions	0.18	0.31	0.46
Collisions	0.00	0.15	0.58
Effective Green Time	N/A	0.08	0.38
Min Green Time	0.18	0.15	0.38
All-Red Time	0.06	0.15	0.33
Phase	0.00	0.00	0.33
Yellow Time	0.00	0.23	0.38

Appendix G: Misconceptions and Contexts by the Percent of People within a Cohort

	Misconceptions:	Percentage of people with Misconception within Cohort (Number of People with Misconception in Cohort) Novice Students (n=17):	Expert Students (n=13):	Practicing Engineers (n=24):
Hypothesized Trend	Approach Speed	65% (11)	38% (5)	17% (4)
	Warrant References	65% (11)	23% (3)	0% (0)
	Cycle Length	47% (8)	54% (7)	17% (4)
Expert Students as the High Misconception	Coordinated Characteristics	29% (5)	46% (6)	17% (4)
	Yellow Time	12% (2)	38% (5)	17% (4)
	Actuated Characteristics	18% (3)	46% (6)	25% (6)
	Vehicle Detection	18% (3)	54% (7)	13% (3)
	Phase	18% (3)	62% (8)	21% (5)
	Gaps	18% (3)	31% (4)	21% (5)
Reverse Hypothesized Trend	Min Green Time	N/A (1)	8% (1)	33% (8)
	Passage Time	N/A (0)	8% (1)	29% (7)
	Semi-Actuated	N/A (0)	31% (4)	42% (10)
	Vehicle Volume	12% (2)	23% (3)	21% (5)
Equal Levels of Misconceptions	All-Red Time	35% (6)	31% (4)	29% (7)
	Effective Green Time	N/A (0)	69% (9)	67% (16)

	Contexts:	Cohorts (Percentage of people with Context within Cohort) Novice Students (n=17):	Expert Students (n=13):	Practicing Engineers (n=24):
Hypothesized Trend	Cycle Length	6%	31%	63%
	Vehicle Detection	12%	15%	38%
	Actuated Characteristics	0%	8%	38%
	Pretimed Characteristics	6%	15%	38%
	Coordinated Characteristics	18%	31%	50%
	Vehicle Volumes	6%	8%	50%
	Future Conditions	18%	23%	42%
	Collisions	0%	15%	46%
	Effective Green Time	N/A (0%)	8%	29%
	Min Green Time	N/A (18%)	15%	38%
	All-Red Time	6%	15%	25%
	Yellow Time	0%	23%	25%
Unusual Trends.	Approach Speed	24%	15%	33%
	Phase	0%	0%	21%
Unexpected Trend: Novice Students with the highest concepts.	Safety	47%	0%	21%
	Cost	41%	8%	17%
	Timing Plan	29%	0%	0%

Appendix H: Misconception Code Details

The 'Frequency of Codes' column shows the number of codes used (same as the number of quotations), and is NOT necessarily the same as the number of people with the code.

Approach Speed Misconceptions:

Novice Student's Approach Speed Misconceptions Code Details:	**Frequency of Codes:**
In order to determine the approach speed, take the average car speed.	5
Equations are used to find speed of vehicles approaching the intersection.	1
High Speed facilities can have a lower clearance time, because the intersection gets cleared faster.	1
In order to determine the approach speed, take the average car speed and the standard deviation.	1
In order to determine the approach speed, take the average car speed or the maximum car speed.	1
Speed determined from speed limits.	1
Speed of vehicles approaching intersection is not important for the decision on installing a traffic signal, because vehicles will end up stopping eventually.	1
Higher speeds make installing a signal more necessary.	2

Expert Student's Approach Speed Misconceptions Code Details:	**Frequency of Codes:**
It is the average speed that is measured from the spot speed study and is used for design.	1
Posted speed is an advisory speed.	1
Do not need speed of approach for the traffic signal justification process.	1
High speeds help justify a traffic signal.	1
Average speed is one consideration for justifying signals.	1

Practicing Engineer's Approach Speed Misconceptions Code Details:	**Frequency of Codes:**
In order to determine the approach speed, take the average speed of 85% of the drivers.	1
Posted speed is the 85th percentile speed.	1

Speed data is irrelevant for signal justification.	1
Typically the posted speed limit is used for analysis and not the actual speed observed at the field.	1

Warrant References Misconceptions:

Novice Student's Warrant References Misconceptions Code Details:	Frequency of Codes:
Contact local government or case studies for traffic signal justifications.	1
Find signal justifications through city database or the City Corps of Engineers.	1
Look at local, state, federal codes.	1
Look up references on Google.	1
Newspapers can provide reference information for the installation of a new signal.	1
Textbooks would be a good reference on the justifications for installing a new signal.	1
The course textbook would be a good reference on the justifications for installing a new signal.	1
There are probably codes.	1
Traffic signal justifications can be found through city or state government.	1
Use books, internet, WSDOT and correlate with all of these.	1
Use data from the state's department of transportation.	1

Expert Student's Warrant References Misconceptions Code Details:	Frequency of Codes:
Download warrant information from ITE website.	1
TSTM is a guideline for traffic signal justifications.	1
Highway Capacity Manual provides guideline for signal warrants.	1

Cycle Length Misconceptions:

Novice Student's Cycle Length Misconceptions Code Details:	Frequency of Codes:
The determination of the cycle length is the same for an isolated intersection and a coordinated intersection.	3
Does not fully understand cycle length, maybe thinks cycle length is green time.	2
Student does not understand cycle length.	1
Coordinated- Cycle length should be sporadic.	1
Coordinated -Decrease the cycle length in coordinated intersections versus isolated intersections.	1

Expert Student’s Cycle Length Misconceptions Code Details:	Frequency of Codes:
Coordinated- Distance between intersections and the speed go into the calculation of cycle length for each intersection.	1
Coordinated- Intersections can have different cycle lengths in a coordinated corridor.	1
Coordinated- The cycle lengths of all intersections can be different from each other.	1
Coordinated -The cycle lengths of all intersections never require to be the same.	1
Coordinated -To estimate the cycle length for the corridor the volume at a point right before the first intersection should be considered.	1
Coordinated -It has to be the same for all intersections.	1
Isolated -Crash history/type contributes to the cycle length.	1
Isolated -The approaching traffic speed is used to help determine the cycle length.	1
Isolated -There is a minimum cycle length for an actuated signal.	1
Isolated -Volume is the only factor that controls the cycle length.	1
Isolated -Directional distribution of traffic affects the cycle length.	1

Practicing Engineer’s Cycle Length Misconceptions Code Details:	Frequency of Codes:
Coordinated- It has to be the same for all intersections.	1
Coordinated- There is an equation to determine the cycle length for coordinated system.	1
Isolated- Cycle length can vary based on phase order.	1
Isolated- There is no such thing in an isolated actuated system.	1
Isolated-Did not mention Delay as being important for the cycle length.	1

Coordinated Characteristics Misconceptions:

Novice Student’s Coordinated Characteristics Misconceptions Code Details:	Frequency of Codes:
The 1st signal has a detector, and that detector starts the coordinated phase for the 1st signal and all the other intersections follow.	3
All signals turn green at the same time.	1
Coordinated signals do not use vehicle detection.	1
Detectors tell computer where platoons are located and how fast they are going.	1

Expert Student's Coordinated Characteristics Misconceptions Code Details:	Frequency of Codes:
Actual driving speed of the drivers control the signal timing.	1
Coordinated signals are always pre-timed, they cannot be actuated.	1
Coordinated signals cannot be actuated, except for the first intersection in the system.	1
Coordinated system mostly deals with through movement, and it does not have enough turning movements to worry about.	1
Intersection geometry plays role in coordination.	1
Termination of an actuated coordinated phase depends on side street demand.	1
At an actuated coordinated signal the coordinated phase terminates by gaps.	1

Practicing Engineer's Coordinated Characteristics Misconceptions Code Details:	Frequency of Codes:
More loss time in a coordinated signal than an isolated signal.	1
Coordinated phases are allowed to gap out once the queue is cleared.	1
Coordinated signals are generally actuated.	1
Coordinated signals are usually semi-actuated.	1
Pedestrian flashing don't walk is a controlling parameter for signal coordination.	1
Signals with more than four legs can not be coordinated.	1
Termination of an actuated coordinated phase depends on side street demand.	1

Yellow Time Misconceptions:

Novice Student's Yellow Time Misconceptions Code Details:	Frequency of Codes:
If a demographic is more likely to accelerate through yellow, then should have a longer yellow light.	1
Yellow needs to be longer when the flow rates are high.	1
Yellow time can be shortened if no vehicles are approaching.	1

Expert Student's Yellow Time Misconceptions Code Details:	Frequency of Codes:
Calculation procedure of yellow and AR duration differ between isolated and actuated signals.	1
The purpose is to let the vehicle go through the intersection.	1
Yellow time in a coordinated signal has to still consider synchronization.	1
Yellow time is usually estimated with rule of thumb than an actual calculation.	1
Dilemma zone is the area right before the stop bar or cross walk from where a	1

vehicle can't safely stop if yellow is displayed.	

Practicing Engineer's Yellow Time Misconceptions Code Details:	**Frequency of Codes:**
The calculation method based on speed can create too much yellow time.	1
It is a waste because the all-red gets the vehicle through the intersection.	1
It is used to avoid the dilemma zone.	1
The purpose is not just to clear the intersection of the vehicles but also of the pedestrians.	1
The purpose is to let the vehicle go through the intersection.	1
The purpose is to let the vehicle go through the intersection.	1

Actuated Characteristics Misconceptions:

Novice Student's Actuated Characteristics Misconceptions Code Details:	**Frequency of Codes:**
Make sure each phase has a reasonable amount of "wait time."	1
There is a Maximum Red time for every phase.	1
Signal times the waiting time on a detector, and tries to minimize that wait time.	1

Expert Student's Actuated Characteristics Misconceptions Code Details:	**Frequency of Codes:**
Actuated signal operates like a stop control intersection as it almost always makes a vehicle stop.	1
Actuated signals count the number of cars, whereas, pre-timed signals don't.	1
Actuated signals work in first come first served basis.	1
After the minimum green time the phase is timed until the end of maximum green.	1
Different timing plan for different time of the day is not required for an actuated signal.	1
Green time for the street with high flow will be extended if the other street has low flow.	1
If a certain approach in an actuated signal is given priority over the others, then the minor approaches could be on a set time.	1
If there is no detection on any approach, all the lights will always be red.	1
There is an algorithm that controls the timing based on queue lengths and historic data.	1
At an actuated signal the phase is terminated either by the presence of a vehicle or by maxing out the green.	1
After the minimum green, a vehicle needs to be present on conflicting approach to terminate the phase even if there is no longer any demand for that	1

phase.	

Practicing Engineer's Actuated Characteristics Misconceptions Code Details:	**Frequency of Codes:**
Actuated Signals only terminated by maxing out	1
Did not mention that a signal can terminate by max out.	1
An actuated signal with low demand will default to pre-timed.	1
Actuation is done to allow for progression along a corridor.	1
Full actuation of a signal is not justified for an intersection with high peak-hour volume and very low volume for the rest of the day.	1
Fully actuated signal doesn't allow for progression along a corridor.	1
Fully actuated signals always require advanced detectors.	1
Fully actuated signals works like a four-way stop control, first-come-first-served.	1
If there is no detection on a minor approach and it is skipped for a couple times, it should be given green lights considering that there might an issue with detection.	1

Vehicle Detection Misconceptions:

Novice Student's Vehicle Detection Misconceptions Code Details:	**Frequency of Codes:**
There are detectors inside the intersection.	1
Vehicle detection times other phases off when a call has been placed a certain amount of time on the detector on one of the opposing phases.	1
When a vehicle gets detected, it gets in line to be served.	1

Expert Student's Vehicle Detection Misconceptions Code Details:	**Frequency of Codes:**
Advanced detectors should always be used in a fully actuated signal if budget allows.	1
Advanced detectors are installed to measure the speed.	1
Advanced detectors would detect a vehicle that is too close to the intersection and extend the yellow to let the vehicle cross the intersection.	1
Detectors compute the delay at the intersection.	1
If an advanced detector detect a vehicle, it'll drastically shorten the other phase that was being timed.	1
The green is reset to the passage time as a vehicle hits the stop-bar detector, even if there's an advanced detector present.	1
Length of the detection zone has no effect on phase termination.	1

Advanced detectors are installed to detect a queue before starting the green.	1
A vehicle approaching the stop bar is detected and it activates the yellow signal, which eventually terminates the phase.	1
The presence of a vehicle on a minor approach can immediately terminate the major street phase if it was being timed for a while.	1
Longer detection zone cuts the green short for a phase.	1
The phase gaps out by the presence of a vehicle on the conflicting approach.	1

Practicing Engineer's Vehicle Detection Misconceptions Code Details:	**Frequency of Codes:**
Detectors detect the actual demand at the intersection.	1
Length of the detection zone has no effect on phase termination.	1
Longer detectors can switch phase earlier.	1
Stop-bar detectors are never used to detect gaps between vehicles.	1
There's always an advanced detector on the minor street.	1

Phase Misconceptions:

Novice Student's Phase Misconceptions Code Details:	**Frequency of Codes:**
The phase sequence always lets the left turns go first.	1
The phase sequence is the same for all BUSY intersections.	1
The phase sequence is the same for all intersections.	1

Expert Student's Phase Misconceptions Code Details:	**Frequency of Codes:**
There are three phases, such as green phase, yellow phase, and red phase.	3
A phase is an interval.	1
A phase is either the red time, yellow time, or green time.	1
Conflicting movements can be at the same phase.	1
Phase is the green cycle for a specific movement.	1
The minimum number of phases at a four leg intersection is four, and the maximum is twelve.	1
There are three phases, such as green phase, yellow phase, and red phase.	1

Practicing Engineer's Phase Misconceptions Code Details:	**Frequency of Codes:**
Does not fully understand Phase Splits.	1
Phase splits are used to hold approaches and to allow approaches to move through intersection.	1
Green portion of the split is not always equal to max green.	1

Split is equal to the green time of a phase.	1
A phase is a time.	1
It is a signal timing parameter.	1
Phase terminates at the end of AR.	1

Gaps Misconceptions:

Novice Student's Gaps Misconceptions Code Details:	**Frequency of Codes:**
Gaps are not important for the decision of installing a new signal.	1
Gaps are not important for the decision of installing a new signal (Question may have confused this student).	1
Gaps are not important unless someone complains about it.	1

Expert Student's Gaps Misconceptions Code Details:	**Frequency of Codes:**
Gaps between vehicles is not an important consideration for signalizing an intersection.	1
A distinct gap size for each movement can be considered (without studying the gap acceptance behavior) as the deciding factor.	1
Gap data is used as a check for different signal warrants, i.e., a signal will be warranted if there's less than a certain number of gaps.	1
A distance of 50 feet is a large enough gap. Did not mention speed.	1
Gaps between vehicles only matter for pedestrian crossing not for vehicular movement.	1

Practicing Engineer's Gaps Misconceptions Code Details:	**Frequency of Codes:**
Gap data for warrants is for passage time.	1
A distinct gap size for each movement can be considered (without studying the gap acceptance behavior) as the deciding factor.	1
Phasing is related to signal warrant process.	1
One of the warrants is to determine the gap sizes on through traffic for the left-turning vehicles.	1
Headway and the gap between detections is same.	1

Min Green Time Misconceptions:

Expert student's Min Green Time Misconceptions Code Details:	**Frequency of Codes:**
The purpose is to let the vehicles on minor road use the green more.	1

Practicing Engineer’s Min Green Time Misconceptions Code Details:	Frequency of Codes:
Does not fully understand Minimum green time.	1
Minimum green is tied to minimum ped time (NOT for actuated signals).	1
Minimum Green Time is associated with red times and is used for pedestrians.	1
Purpose is to get at least somebody through intersection.	1
Purpose is to serve a reasonable number of vehicles.	1
Purpose is to serve an anticipated number of vehicles.	1
Purpose of min green time is To clear the queue.	1
The min green is to allow a certain number of cars through.	1
The purpose is to reduce delay and queues.	1

Passage Time Misconceptions:

Expert student’s Passage Time Misconceptions Code Details:	Frequency of Codes:
Passage time is used to extend the yellow time if a vehicle is detected in the dilemma zone.	1

Practicing Engineer’s Passage Time Misconceptions Code Details:	Frequency of Codes:
Engineer did not mention queue clearance.	2
Passage Time is the time between the minimum green and the maximum green.	1
Passage Time is used for safety.	1
It is the time for a vehicle to travel between loops.	1
It's the time to pass from the upstream to the stop bar detector, so for no advance detector there's no such thing as passage time.	1
Its purpose is to know how long it would take a vehicle to cross the intersection once it is detected by an advanced loop.	1
Passage time is to terminate the phase and vehicle extension time is to give more green.	1

Semi-Actuated Misconceptions:

Expert student’s Semi-Actuated Misconceptions Code Details:	Frequency of Codes:
Detectors are placed on the major street, and not on the minor street.	1
It is a hybrid of pre-time and actuated.	1
The major street green will stop after a certain time, i.e., the signal gets "more	1

green" but it's not always set to green.	
¦ Signal Types-Misconception-Semi-actuated signals have a fixed green time on some approaches.	1

Practicing Engineer's Semi-Actuated Misconceptions Code Details:	**Frequency of Codes:**
Main movement has a set timing for a semi-actuated control.	1
Main movement has a set timing for a semi-actuated control.	1
Semi-Actuated signals will max out a leg if that leg is receiving more vehicles than normal. Also Semi-Actuation is based on actuation. (Both are partial Misconceptions)	1
There is a fixed cycle length for a semi-actuated signal.	1
As the signal always turns green on minor street, there's more lost time, and thus it is less efficient operation than fully actuated signal.	1
Both streets have detectors to detect vehicle presence.	1
Cycle length is constant for semi-actuated signal.	1
Having no detectors on major road for semi-actuated control doesn't make sense as the volume on major street goes down during off-peak hours.	1
It is also called actuated coordinated, it typically has coordination in one direction and then actuation in the other direction.	1
Major street gets a fixed amount of green time.	1
Semi-actuated signal is aimed at creating a green band along a coordinated corridor.	2
The signal has to cycle through all the phases, however, the actual duration of green provided to the phases will vary based on traffic demand.	1
There's a dedicated phase for the minor street that always get green at least for a short duration regardless of vehicle presence.	1
Coordinated means semi-actuated.	1

Vehicle Volumes Misconceptions:

Novice Student's Vehicle Volumes Misconceptions Code Details:	**Frequency of Codes:**
If no traffic data is available, then guess the data and adjust signal in the field.	1
If no traffic data is available, then you can get a permit to build it.	1

Expert Student's Vehicle Volumes Misconceptions Code Details:	**Frequency of Codes:**
If the signal is warranted based on other factors, volume data is not required.	2
Annual average daily traffic volume is needed, thus the data should be collected for a year.	1

If possible, then one year traffic data needs to be collected.	1
If the signal is warranted based on other factors, volume data is not required.	1

Practicing Engineer's Vehicle Volumes Misconceptions Code Details:	**Frequency of Codes:**
If no traffic volume data is available, then you can look at other warrants.	1
Only weekday volumes are important.	1
Considering only peak hour volume might be enough to justify a signal.	1
Fifteen minute interval data for 24 hours is required.	1
Only left-turning volume is important for signal warrant.	1
Take the daily, weekly or seasonal fluctuation in demand into account.	1
Off-peak hour conditions can be assumed from peak hour data.	1

All-Red Time Misconceptions:

Novice Student's All-Red Time Misconceptions Code Details:	**Frequency of Codes:**
Does not fully understand that there is an all-red time.	5
All Red should be longer when the flow rates are high.	1
All-Red time can be shortened if no vehicles are approaching.	1
If there is an all-red time, its purpose is to clear for pedestrians.	1

Expert Student's All-Red Time Misconceptions Code Details:	**Frequency of Codes:**
All-Red time placement may depend on if the signal is isolated or coordinated.	1
Duration of red depends on the traffic volume at the intersection.	1
Used to make the intersection clear of pedestrians.	1
There is an equation to calculate the AR that has a grade component in it.	1

Practicing Engineer's All-Red Time Misconceptions Code Details:	**Frequency of Codes:**
All red may not be necessary, depending on the volumes.	1
All-Red depends on the drivers anticipation.	1
All-Red is not used for clearance.	1
All-Red time should increase when there is a higher accident incidence.	1
The All-red time can be shortened for a coordinated intersection.	1
The yellow and all-red time lengths are inversely related.	1
AR is used to let the vehicles that are at the dilemma zone go safely go through the intersection.	1
Isolated signal has longer AR than coordinated signal.	1

It is the extension of yellow.	1
Used to make the intersection clear of pedestrians.	1

Effective Green Time Misconceptions:

Expert Student's Effective Green Time Misconceptions Code Details:	Frequency of Codes:
Effective green time=Total green duration-start-up lost time.	3
Did not mention that Yellow and All-Red is involved in the Effective Green Time.	1
Effective green time for a car waiting at the end of the queue is shorter than the one at the front.	1
Effective green time=Total green duration-start-up lost time.	1
Estimation of effective green can be effected by the local law on yellow, such as restrictive or permissive yellow.	1
Estimation of effective green for a phase in a coordinated signal is different than isolated signal.	1
Subtract part of the clearance lost time from the green time to determine the effective green time.	1
Vehicles do not need to move freely during the effective green time.	1
Effective green time=Green duration-(Y+AR).	1

Practicing Engineer's Effective Green Time Misconceptions Code Details:	Frequency of Codes:
Effective Green Time for a coordinated system is the min green or max green time.	1
Effective Green Time is the capacity of a movement.	1
Effective green time is the green time.	2
Gapping out frequently means that signal is not efficient.	1
Loss time is the startup plus the AR and yellow time.	1
Purpose of the effective green time is for vehicle progression.	1
Wrong about the definition of effective green time.	1
Effective green is the actual duration for which the signal is green for a phase in an actuated signal.	2
Effective green is the green time allocated for movements.	1
Effective green is the minimum green.	2
Effective green time depends on the demands at the intersection.	1
Effective green time is a software-specific terminology.	1
Effective green time=Split for the phase-Clearance interval (Y+AR).	1
Effective green time=Split for the phase-Clearance interval + The portion of the clearance interval utilized by the vehicles.	1

For isolated intersection it varies, but for coordinated signal it's the same in every cycle.	1
For the effective green time, the portion of clearance lost time that is utilized by the drivers, should be excluded as the signal indication is not green.	1
If the movement is stopped during the green due to any reason, then that time should be subtracted from green to get effective green time.	1
It is to serve the traffic waiting on the cross street.	1