Traffic Signal System Misconceptions Across Three Cohorts

Novice Students, Expert Students, and Practicing Engineers

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Both research evidence and theories of situated knowledge suggest that students are not prepared for the engineering workforce upon graduation from engineering programs. Concept inventory results from diverse fields also suggest that students do not understand fundamental concepts of engineering, mathematics, and science. These concerns may result from different knowledge deficiencies: one from a lack of conceptual understanding and the other from a lack of applied knowledge. In an attempt to explain the patterns in misconceptions across three cohorts, the research goals of this paper are to identify misconceptions (knowledge about phenomena that are persistent and incorrect) related to traffic signal operations and design across the cohorts of novice engineering students, expert engineering students, and practicing engineers. Results indicate three misconception patterns (decreasing, increasing, and no change) across the three cohorts. The pattern of decreasing misconception can be explained by a traditional model of learning that suggests improved understanding with additional instruction and student time on task. The pattern of increasing misconception appeared for concepts that are particularly complex and confounding; practicing engineers produce much more complex answers that are mostly correct but include leaps and speculations not yet proven in the literature. Misconception frequencies that stay the same tend to include topics that do not have required national standards or that are buried in automated processes. The process of identifying and documenting misconceptions that exist across these cohorts is a necessary step in the development of a data-driven curriculum. An example of a conceptual exercise developed from four misconceptions identified in this study is also demonstrated.

Traffic signals are a critical component of transportation infrastructure because they directly contribute to the safety and efficiency of the surface transportation system. Transportation safety is traditionally concerned with the minimization of crash frequency and severity on the nation's roadways. These crashes are influenced by three system components: the driver, the vehicle, and the built environment. Civil engineers have the unique ability to directly manipulate the built environment, all the while needing to understand the associated human factors and vehicle capabilities. In 2010, approximately 36% of all crashes occurred at signalized intersections and represented approximately 787,236 crashes (*1*). In 2004, NCHRP Report 500, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 12: A Guide for Reducing Collisions at Signalized Intersections suggests that the use of traffic control and operational improvements have the greatest likelihood to improve safety at signalized intersections (*2*).

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CHALLENGES IN TRAFFIC SIGNAL EDUCATION

Traffic signal operations can be described as either pretimed (fixed timing determined a priori), semiactuated (detection for some traffic movements, with timing based on traffic demand), or fully actuated (detection for all traffic movements). Regardless of the type of signalized intersection, much of the core conceptual knowledge is transferable between these intersection types. It is those cross-cutting concepts that have been the focus of this study. Preparation to solve complicated transportation issues related to the safety and efficiency of traffic signals requires deep conceptual knowledge of these cross-cutting transportation fundamentals. This content area is particularly difficult for civil engineering students because they possess numerous preconceptions about traffic signal system processes from their driving or riding experiences—and the logic of the processes are embedded in the software and hardware in a traffic controller cabinet. Much of the content is highly confounded, i.e., many design parameters are related to other design parameters (e.g., the setting of passage of time is dependent on the length, placement, and operation of the detector as well as the speed and classification of approaching vehicles). Furthermore, traffic patterns and driver behavior, which are important considerations in the design and operation of traffic signals, vary widely and, unlike many design parameters in other engineering disciplines, they are difficult to predict with mathematical models. This phenomenon makes traffic signal education challenging for students, educators, and practicing engineers.

BACKGROUND

Individuals make sense of new information in terms of what they already know, including a myriad of existing impressions, beliefs, assumptions, and models of phenomena (*3*). Learning, then, is not just a process of gaining new knowledge, but also of revising existing knowledge. Existing knowledge can originate from everyday experiences or from instruction (*4*). For example, in the study of kinetics and kinematics in physics, students bring a lifetime of experience of observing objects move in the world (*5*). The same is true of transportation engineering, specifically referencing the behaviors of drivers and the movement of vehicles on roads and through intersections. Most individuals, from a very young age, have observed the movement of vehicles on roadways. Misconceptions are knowledge about phenomena that are persistent and incorrect (*6*). Research conducted over the past 20 years in physics and engineering education has illustrated students' misconceptions in physics (*7*), statics (*8*), mechanics of materials (*9*), statistics (*10*), thermodynamics (*11*), and transportation engineering (*6, 12*). Because most engineering students and practicing engineers have extensive interactions with the transportation system, it is expected that they also will have misconceptions related to signal operations and design. This expectation is due to the fact that many of the elements that govern the control of a signalized intersection, such as timing processes or detector activations, do not provide directly observable feedback to the traveling public. Additionally, from the perspective or context of traveling through an intersection from a single approach, many elements, such as the inclusion of a red clearance interval, may not be directly observable.

An explicit assumption of most research related to misconceptions is that a correct conceptual understanding would relate to the ability to apply this conceptual knowledge to other settings and contexts, basically a cognitive approach. This assumption is important because it means that if engineering students understand the central concepts, they will be able to use them in engineering practice. However, situated cognition theories suggest that knowledge is not comprised of fundamental concepts that are applied in different contexts, but that knowledge is related to application and context. Knowledge is embedded in and related to the social environment in which it is learned, and preparation for practice should be in an environment that is authentic to that practice (*13, 14*). For example, the average 17-year-old has learned vocabulary at a rate of 5,000 words per year, or 13 words per day, through everyday experiences of talking, listening, and reading. In contrast, students learn between 100 and 200 words per year through formal classroom instruction, using tools such as vocabulary lists (*13*). Another example includes shoppers who were found to be nearly perfectly proficient (about 98% correct) with algebraic concepts within the context of grocery shopping but far less competent (about 50% correct) when asked about the same mathematical concepts absent the context of the grocery store (*15*). Previous results in transportation engineering show that practicing engineers include three to four contexts such as features of the roadway and the surroundings in definitions of fundamental concepts of sight distance and stopping sight distance, as compared with engineering faculty, who mostly include no context in their definitions (*16*).

Differences between conceptual understanding and situational learning have been described as the cognitive–situational divide by learning theorists (*17*): on the cognitive side experts believe that it is concepts that are important to learn and are the core of individuals' understanding, while on the situative side it is the situation in which concepts are applied that is the prominent feature of understanding. In engineering, as compared with sciences such as physics, it is likely that contextual, or embedded, features are even more important to learning and knowing because of the applied nature of work and the social, legal, and other factors that often dictate solutions. However, there is very limited research comparing engineering student and practicing engineer in the understanding of engineering concepts; therefore, illuminating the importance of concepts versus contexts will contribute to the body of knowledge. This study explores differences in the thinking of students and practicing engineers regarding concepts related to transportation engineering in an attempt to begin to understand the cognitive–situational divide in engineering. These results have important implications for curriculum and instruction in engineering, specifically relating to the importance of focusing on concepts or applications.

RESEARCH GOALS

The goals of this research are to determine engineering student and practicing engineer misconceptions related to traffic signal design; explain patterns in misconceptions across the categories of novice student, expert student, and practicing engineer; and demonstrate data-driven curriculum design through the application of misconceptions to conceptual exercises.

METHODOLOGY

The overall methodologies used in this study are shown in Figure 1 and include the development of concepts to be studied using a modified Delphi method, interview protocol development, interview methodology, and data analysis procedures.

Concept Selection: Modified Delphi Method

The concepts related to traffic signal systems examined in this research were determined in an iterative process with experts in the field of transportation engineering from around the country (Figure 1). All participants were asked to individually identify traffic signal systems concepts that they deemed important to traffic signal systems. Webinars were then conducted with four experts each. Prior to the webinar, each webinar group's individual responses were consolidated into a single list, resulting in each webinar group having a unique list of concepts. During each webinar, experts discussed the importance of listed concepts and developed consensus on the importance (high, medium, or low) of each concept. Each webinar resulted in a list of concepts sorted into the three importance categories. All concepts were then sorted into three importance categories using the ranking for each concept from the individual webinars and the four highest ranking concepts (listed in the following methodology section) were selected for investigation in this research project.

Subject Recruitment and Sample Size

Interview participants consisted of three cohorts: practicing engineers, expert students, and novice students. The first cohort included 24 practicing engineers: 10 from Spokane, Washington; 12 from Portland, Oregon; and 2 from Boise, Idaho. Both private- and public-sector practicing engineers with a range of 1 to 28 years of experience were interviewed. The second cohort included 13 expert students from Oregon State University. Expert students had taken at least one graduate-level course in traffic engineering. The third cohort consisted of 17 novice students from Washington State University. Novice students had either completed the introduction to a transportation engineering course or were currently enrolled in the course when interviewed.

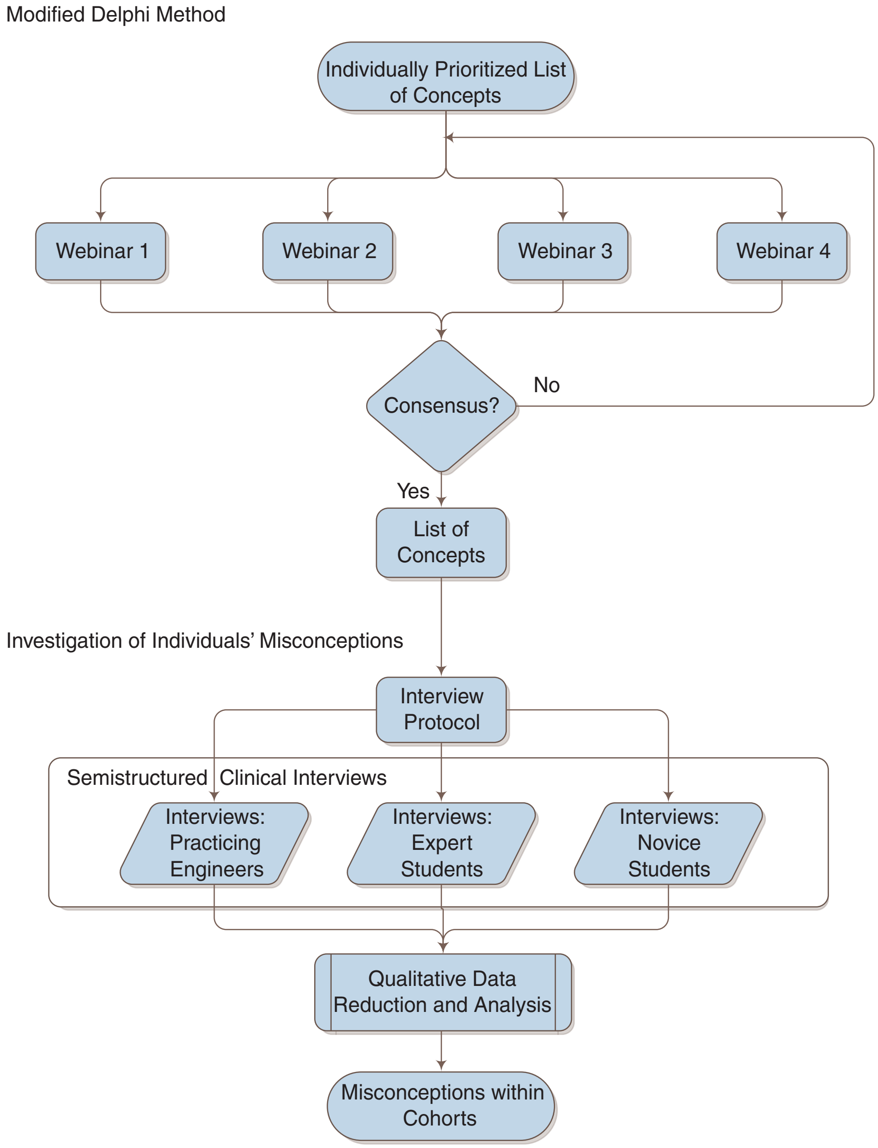


FIGURE 1 Flowchart of Delphi method and clinical interviews.

Protocol Development and Implementation

A semistructured interview protocol (*18*) was developed using the selected concepts of traffic-signal justification (called signal warrants by experts), signal timing, traffic signal phasing, and timing parameters. It could be argued that these are not necessarily concepts, but rather content areas. This concern is mitigated by the wording and focus of the interview questions. For example, questions such as "What is traffic signal justification?" were not asked; but, rather, those which would more naturally lead to a discussion of the concepts relevant to traffic signal justification, "What factors contribute to the decision to place a signal at an intersection?" Semistructured interview protocols include base questions that were asked of all participants, and probing questions that are asked selectively based on interview responses. The interview protocol consisted of 28 core questions and 13 probing questions. An identical interview protocol was used for both the practicing engineer and the expert student cohorts on the basis of their relatively advanced knowledge of the subject. A different interview protocol, with more common and accessible terminology, was developed for novice students based on their lack of technical knowledge related to the content. Care was taken to focus questions on the same underlying concepts in both protocols to generate meaningful responses on the same conceptual content from all three cohorts. The interview protocol was refined and improved through a pilot process to ensure that the protocol could be used as a valid instrument to determine participants' understanding of the transportation concepts.

Clinical interviews, an open-ended style of interview, were used in this study to elicit interview participants understanding of core concepts (*19*). The clinical interview is focused on uncovering an individual's way of thinking about an idea, and is based on the assumption that individuals have unique features of their understanding. The clinical interview method with a semistructured protocol allows the interviewer the required flexibility to ask probing questions to elicit individualized meanings in the interview on the basis of interviewees' responses.

Interviews lasted from 45 to 60 min for practicing engineers and expert students, and about 30 min for novice students. In total, 48 hours of clinical interviews were conducted and transcribed, resulting in 975 pages of interview data for qualitative analysis.

Qualitative Data Reduction

Transcribed interview data were coded and analyzed using the qualitative data analysis and research software, Atlas TI (*20*). With the goal of identifying misconceptions, interviews were coded for the correctness of responses. For the purposes of this research, misconceptions were considered to be anything verbalized by respondents that was incorrect and detailed enough to be understood. Biweekly discussions were held between two researchers; one at Oregon State University and the other at Washington State University, for the purpose of establishing coding consistency. The outcome of approximately two months of meetings and the iterative refinement of the coding procedure was a set of 58 codes for misconceptions and associated definitions that were used to analyze the remaining interview transcriptions independently. A typical code included two components: the general topic, and the description of the misconception. For example, "cycle length-coordinated-concept-misconception—it has to be the same for all intersections." In this example, "cycle length-coordinated" describes an interviewee misconception about the cycle length of coordinated traffic signals; and the phrase, "It has to be the same for all intersections," provides additional details of the misconception. This is a misconception because there are cases in a coordinated corridor where, due to large differences in volumes at subsequent signals, cycle lengths may be different, as long as they are an even multiplier of one another. Responses of "I don't know," or "It could be," were not considered misconceptions, but the argument that the duration of red clearance intervals is related to intersection volumes or that approach speed does not factor into the decision to signalize an intersection were classified as misconceptions. Frequencies of misconceptions in each cohort were determined, and all misconceptions that were initiated by at least 30% of the participants from one of the three cohorts were included in the results. Most misconceptions were present in much less than or much greater than 30% of the participants, making it a reasonable choice of threshold to exclude some data from the final results.

RESULTS

For each concept and cohort (e.g., approach speed–novice students) one of four categories was determined: highest, medium, lowest, and not applicable. Categories of highest and lowest were defined first as the cohort within a concept with the highest and lowest percentage of participants with a misconception, respectively. The middle category is the cohort that fit within the highest and lowest categories, and the not applicable category indicates that no individuals within a particular category displayed substantial evidence of a misconception. However, individuals who fell within the not applicable category may not have known the concept. When the percentage of individuals in two cohorts with misconceptions related to a concept was within 15% (e.g., vehicle volumes), they were considered to be approximately equivalent.

Four noticeable trends, as shown in Tables 1 through 4, were found when comparing the categories across cohorts for each concept.

TABLE 1 Misconceptions and Quotations, Trend 1

	Cohort Number of Participants (%)		
Concept	Novice Students ($n = 17$): Highest	Expert Students ($n = 13$): Middle	Practicing Engineers ($n = 24$): Lowest
Approach speed	65 (11)	38 (5)	17 (4)
Cycle length	47 (8)	54 (7)	17 (4)

TABLE 2 Misconceptions and Quotations, Trend 2

	Cohort Number of Participants (%)		
Concept	Novice Students ($n = 17$): Lowest	Expert Students ($n = 13$): Highest	Practicing Engineers ($n = 24$): Medium
Coordinated signals	29 (5)	46 (6)	17 (4)
Yellow change interval	12 (2)	38 (5)	17 (4)
Actuated signals	18 (3)	46 (6)	25 (6)
Vehicle detection	18 (3)	54 (7)	13 (3)
Phases	18 (3)	62 (8)	21 (5)

TABLE 3 Misconceptions and Quotations, Trend 3

	Cohort Number of Participants (%)		
Concept	Novice Students ($n = 17$): NA	Expert Students ($n = 13$): Lowest	Practicing Engineers ($n = 24$): Medium
Minimum green time	NA (0)	NA (0)	33 (8)
Passage time	NA (0)	NA (0)	29 (7)

NOTE: NA = not applicable.

TABLE 4 Misconceptions and Quotations, All Cohorts Approximately Equal, Trend 4

	Cohort Number of Participants (%)		
Concept	Novice Students ($n = 17$)	Expert Students ($n = 13$)	Practicing Engineers ($n = 24$)
Semiactuated signals	NA (0)	31 (4)	42 (10)
Vehicle volume (traffic signal warrants)	12 (2)	23 (3)	21 (5)
Red clearance interval	35 (6)	31 (4)	29 (7)
Effective green time	NA (0)	69 (9)	67 (16)
Gaps	18 (3)	31 (4)	21 (5)

NOTE: n = number; highest = highest percentage of misconceptions; middle = mid-level percentage of misconceptions; lowest = lowest percentage of misconceptions; NA = not applicable.

Tables 5 through 8 display data for each of the four previously identified trends, including common misconceptions and example quotations for each cohort and concept. Example misconceptions shown in Table 5 (e.g., approach speed is determined from posted speed limits) through 8 are summary statements developed by the researchers to represent common misconceptions, and those that cross two cohorts were misconceptions shared by these cohorts. Because of space limitations, misconceptions and quotations were not included for each concept. The selection of concepts to be included here is based on the importance of the misconceptions and the clarity of the associated quotations.

Trend 1. Highest to Lowest Number of Misconceptions: Novice Students, Expert Students, and Practicing Engineers

The percentage of misconceptions related to the concepts of approach speed and cycle length decreased as the expertise of the cohort increased. To explain this pattern of misconceptions across cohorts, approach speed was examined in greater detail. One common misconception regarding approach speed was "approach speed is determined by taking an average of the speeds empirically observed in the field." Eleven of 17 novice students, one of 13 graduate students, and none of the 24 practicing engineers were found to have this misconception.

When approach speed is considered as the operating speed of the road, it is commonly determined by calculating the 85th percentile from spot speed study data collected in the field (*21–23*). Novice students are not familiar with this process and are more prone to propose using the average speed, which is a common descriptive statistic used to measure the central tendency of data sets in numerous classes and alternative contexts in which these students have participated. However, expert students are exposed to the mechanics of calculating an 85th percentile speed as well as its theoretical justification. For example, traffic signal justification is performed by applying the nine traffic signal warrants that require the consideration of the approach speed, as found in the *Manual on Uniform Traffic Control Devices.* All of the expert students interviewed for this study had taken at least one graduate-level transportation engineering course that elaborately covered this topic. Practicing engineers frequently refer to various engineering manuals and design guides where 85th percentile speed is commonly used for design and operational purposes, such as the calculation of the yellow change and red clearance interval durations. Additionally, engineers deal with real-world data for

TABLE 5 Misconceptions for Example Concepts Across Cohorts, Trend 1

Novice Students, Highest	Expert Students, Middle	Practicing Engineers, Lowest
Concept Question, Approach Speed: How Should the Approach Speed of an Intersection Be Determined When Considering Signalization?		
Example misconceptions		
Approach speed is determined from equations.	Posted speed is an advisory speed.	NA
Approach speed is determined from speed limits.	Speed data are irrelevant when considering the signalization of an signalized intersection.	Speed data are irrelevant when considering the signalization of an signalized intersection.
Average speed is used for the approach speed.		Posted speed is the 85th percentile speed.
Example quotations		
Novice student: "Well, if it's just speed I would probably find the mean and standard deviation of speed to figure out an average of how fast are these cars coming into this intersection."	Expert student: "Posted speed is going to give you a rough indication of how fast people are traveling, but I've never met a single driver who drives the exact speed limit. You know, it's an advisory speed."	Practicing engineer: "I feel like most of the work that I did was based on the speed limit, not actual speed data collected in the field. If there's issues with speeding it might warrant actually collecting speed data."
Concept Question, Cycle Length: How Is the Cycle Length Determined at Isolated Signalized Intersections?		
Example misconceptions		
The determination of cycle length is the same for an isolated intersection and a coordinated intersection. Cycle length is the green duration.	Crash history–type contributes to the cycle length. Volume is the only factor that controls the cycle length. There is a minimum cycle length for actuated signal. Cycle lengths for all intersections in a coordinated corridor have to be the same.	There is no such thing in an isolated actuated system. Cycle length can vary based on phase order. There is an equation for coordinated system cycle length.
Example quotations		
Novice student: "Cycle length would be sporadic, I'd imagine. It wouldn't be like a linear amount of time, it would change, had a fluctuation."	Expert student: "The volume on the approach, and the crash history and type of crashes would affect the cycle length, you know, the yellow time and the red time in some way, and then the speed, probably speed more than anything else."	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."

NOTE: NA = not available.

TABLE 6 Misconceptions for Example Concepts Across Cohorts, Trend 2

Novice Students, Lowest	Expert Students, Highest	Practicing Engineers, Lowest
Concept Question, Coordinated Signals: How Does Vehicle Detection Operate in Coordinated Signals?		
Example misconceptions		
All signals turn green at the same time.	Coordinated signals are always pretimed, they cannot be actuated.	Signals with more than four legs cannot be coordinated.
Coordinated signals do not use vehicle detections.	Actual driving speed of the drivers control the signal timing.	More time is lost in a coordinated signal than an isolated signal.
Detectors tell computer where platoons are located and how fast they are going.	Coordinated phases are allowed to gap out once the queue is cleared.	
	Termination of an actuated coordinated phase depends on side street demand.	
The first intersection in a coordinated system is actuated and has detectors.		Coordinated signals are generally actuated.
Example quotations		
Novice student: “I would guess that there would be only one sensor at the first light determining when there’s someone at the light and then it’ll change that light and then the next one and the next until that person or a group of people can get through the lights.”	Expert student: “You can’t have actuation in a corridor, to my knowledge, because, 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.”	Practicing engineer: “Coordinated signals are generally actuated but the difference with isolated signals is that the coordinated signals have to communicate with each other and all of the same cycle length and have to maintain a certain offset from a zero point.”
Concept Question, Yellow Change Interval: How Is the Duration of the Yellow Change Interval Determined?		
Example misconceptions		
Yellow needs to be longer when the flow rates are higher.	Calculation procedure of yellow and AR duration differ between isolated and actuated signals.	It is a waste because the AR gets the vehicle through the intersection.
Yellow time can be shortened if no vehicles are approaching.	Duration of yellow depends on intersection width.	It is used to avoid the dilemma zone.
	Yellow and AR should be longer in isolated intersections.	
	The purpose is to let the vehicle go through the intersection.	
Example quotations		
Novice student: “You would definitely want to make sure that there is a long period of yellow time because if there’s a high flow of people will most likely be rushing to get through the intersection; they want to—so you would want a longer all-red time.”	Expert student: “The yellow time is more based on, you know, the speed that the driver’s traveling and how big the intersections are. And to be completely honest, yellow time is usually done more with a rule of thumb than an actual calculation, for good or ill.”	Practicing engineer: “The yellow time I guess could be used to changing the signal from one phase to another and also to avoid, I guess, the dilemma zone.”

NOTE: AR = all red.

planning, design, and operations and are more familiar with the implication of approach speed in terms of intersection performance and safety.

Trend 2. Highest and Lowest Number of Misconceptions: Novice Students and Practicing Engineers

For the concepts-coordinated signals, yellow change intervals, actuated signals, vehicle detection, and phases, the frequency of misconceptions was found to be highest among expert students; example misconceptions and quotes for coordinated signals and yellow-change interval are shown in Table 6. This trend was not anticipated by the authors because expert students should be more familiar with these concepts from the additional exposure in graduate-level traffic engineering classes. However, topics such as coordinated signals still tend to be covered in somewhat superficial ways, even at the graduate level. While expert students were familiar with the terminology, their depth of understanding was limited enough to generate mistakes in their conceptual understanding.

Novice students either had relatively simple misconceptions such as those shown in Table 6 or demonstrated a near-complete lack of knowledge about these more advanced concepts, with responses such as, “I don’t know.” “I’m not sure.” or “It might work this way.”

The low rates of practicing engineer misconceptions are likely due to the importance of these concepts in professional practice. The topics that presented this pattern (coordinated signals, yellow change interval, actuated signals, vehicle detection, and phases) are all critical elements of traffic signal design and operations, mapping directly to the daily work experience of practicing engineers.

Trend 3. Highest Number of Misconceptions: Practicing Engineers

For concepts of minimum green time and passage time, practicing engineers indicated several misconceptions; however, there was

TABLE 7 Misconceptions for Example Concepts Across Cohorts, Trend 3

Novice Students, NA	Expert Students, NA	Practicing Engineers, Highest
Concept Question, Minimum Green Time: What Function Does the Minimum Green Time Serve?		
Example misconceptions		
Green time can be cut short only by emergency vehicles or a technical issue.	The purpose of minimum green is to let the vehicles on minor road use the green more.	The purpose of minimum green time is to clear the entire queue. Minimum green time is used to reduce delay and queues. Minimum green time is associated with red times and is used for pedestrians.
Example quotations		
Novice student: "There could be a bug in the programming. Maybe an emergency vehicle comes by and it switches or some kind of event perhaps triggered the green to end early."	Expert student: "The minimum green time is used to let the traffic from the other approach use the intersection more."	Practicing engineer: "Minimum green time is so that you're not trapping a car. It's called a yellow trap. You need to make sure you get a certain number of cars through. The minimum green is also tied to the minimum ped-time."
Concept Question, Semiactuated Signals: How Do Semiactuated Isolated Signals Operate?		
Example misconceptions		
NA	Detectors are placed on the major street, and not on the minor street. It is a hybrid of pretime and actuated.	Both streets have vehicle detectors. Cycle length is constant for semi-actuated signal. Coordinated means semiactuated. 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. Major street has a fixed amount of green time in a semiactuated signal.
Example quotations		
Novice student: NA	Expert student: "In a semi-actuated signal, I believe we cycle the timing in favor of the major road, we always put longer green cycle for the major road, because there are a lot of cars there. It is not green all the time, it's just given longer green than the minor road."	Practicing engineer: "Semi actuated is when you typically would have loops on side streets and you wouldn't have them on the main line, and your main is going to get a fixed amount of time."

NOTE: NA = not available.

minimal evidence of misconceptions for novice and expert students in the data set (Tables 1 through 4).

It was evident from the novice student responses that they were not particularly familiar with the minimum green time concept, even from their everyday driving experiences. Two students said that a very short green duration is a rare event that might result from the preemption caused by emergency vehicles, and two other students said that it might happen due to a software or hardware malfunction. However, expert students seem to understand the concept very well, because most of them worked with this concept in graduate course work; only one of thirteen students appeared to show any confusion with the concept.

The most noticeable discrepancy was found in the practicing engineer cohort; four of 24 were able to define the concept accurately, but their perception of the concept was confounded by performance measures such as queue length and delay at the intersection. Traffic engineers deal with these two measures of effectiveness more frequently than any other. Specifically, they often use simulation software to predict the performance of transportation systems. These applications allow engineers to enter timing parameters such as the minimum green time, and in response to those variables and numerous others, the software produces measures of effectiveness such as average delay and queue length. It is possible that this operational procedure has resulted in a way of thinking for some traffic engineers that makes a connection between the minimum green time and those measures of effectiveness.

Trend 4. Equivalent Frequency of Misconceptions Across Cohorts

As shown in Table 8, the trend of cohorts being approximately equal was found in the concepts of vehicle volume, red clearance interval, effective green time, and gaps. Considering the high rate of misconceptions for all of the cohorts, it is possible that these are embedded concepts. As embedded concepts, it is possible that they are not used directly for traffic signal timing, and therefore practicing engineers may not have a need to fully understand these concepts. One such example is effective green time. It is a topic specific to signalized intersection timing and capacity measurement, so the concept is not as explicit as cycle length or maximum green time. Furthermore, because it is not a timing parameter that engineers use as a direct entry to the traffic controller or traffic simulation software, and because the implications often cannot be mapped directly to the signal timing issues, engineers seem to have difficulty recalling and understanding the concept as well. Contributing to the lack of understanding or

TABLE 8 Misconceptions for Example Concepts Across Cohorts, Trend 4

Novice Students	Expert Students	Practicing Engineers
Concept Question, Red Clearance Interval: How Is the Duration of the Red Clearance Interval Determined?		
Example Misconceptions		
Red clearance interval can be shortened if no vehicle is approaching.	Grade of an intersection approach affects the duration of the red clearance interval.	The yellow change and red clearance interval durations are inversely related. Isolated signals have longer red clearance interval than coordinated signals.
Duration of red clearance interval depends on the volume of the intersection.		
The purpose of using a red clearance interval is to clear the pedestrians of the intersection.		
Example Quotations		
Novice Student: "If the sensors don't detect any cars on one street and a lot of the other, they could lower the all red time; it could be lowered, the yellow time as well as the allocated green time just to speed up the process."	Expert Student: "I mean, I think you have to look at all-red by an intersection-by-intersection basis. Because some intersections—say they have low volume of traffic—aren't going to need to have that."	Practicing Engineer: "All red is really an option. You don't have to do all red. The City of Spokane does mainly for clearance and to make sure that everyone is set before you give them the green time. In an isolated intersection, all red may not even be necessary depending on the volumes."
Concept Question, Traffic Volume: How Are Traffic Volumes Considered When Justifying a Traffic Signal?		
Example Misconceptions		
If no traffic volume data is available, then it can be guessed and adjusted in the field based on signal performance. A traffic signal can be approved for installation even if there is no traffic volume data.	Traffic signal warrants require AADT, thus the traffic volume should be collected for at least one year for that matter. If the signal is warranted based on other factors, volume data is not required.	Only weekday volumes are important for traffic signal warrants. Considering only peak hour volume might be enough to justify a signal. Only left-turn volumes are important for signal warrant.
If the traffic volume data is not available for an intersection, installing a signal can still be justified based on other warrants.		
Example quotations		
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."	Expert student: "Volume data is probably used in four of the nine MUTCD warrants or so and then there's another five that could be maybe looked at without volume."	Practicing engineer: "I think traffic signal justification is primarily based on left turning volumes, but I suppose there could also be safety concerns as well. But I think it's mainly left turning volumes."

NOTE: AADT = annual average daily traffic; MUTCD = *Manual on Uniform Traffic Control Devices*.

creating misconception about this concept across all three cohorts could be the reality that effective green time is related to a number of other concepts, such as start-up lost time, green duration, cycle length, and clearance lost time. Additionally, many of these variables are concepts related to the *Highway Capacity Manual,* which may be obscure for engineers not directly involved in the manual's application.

Although, most engineers were at least familiar with the terminology, one believed that it was software-specific. Some engineers believed that the effective green time was actually the duration of green signal, which suggests a lack of familiarity with effective green time. However, in a few instances, engineers were found to have a deeper understanding of the concept but eventually drew an incorrect conclusion while trying to draw connections between different elements of the effective green time equation. For example, one of the engineers stated the following:

> "I believe it's the min. green time [effective green time]. I think your effective green time is where you would. . . . Okay we're gonna run our green time of twelve seconds, then we have the ability to extend it to fifteen seconds if the volume is there, but your effective green time is the minimum green time, that would be if your signal would, I think it would, be under the scenario where the signal is running free as opposed to be in like the set up with specific timing. Your effective green is your min green, and then it can extend. Does that make sense?"

This statement suggests that the subject has connected the effective green time directly to the green time and proceeds to relate that time to various timing parameters that would influence the duration of green time for a particular movement at an actuated signal.

FINDINGS

Findings suggesting that students have misconceptions are relatively less surprising than findings that practicing engineers have misconceptions. It is common, at least by academics, to presume that practicing engineers are masters of their practice and would not hold some of the same misconceptions as students. These findings may be explained through the lens of the cognitive–situational divide in transportation engineering, which requires examining what students and practicing engineers know about fundamental traffic signal concepts and how they may use or relate these concepts to their current context (e.g., driving experience or application to design). The most striking evidence is a comparison between the advanced concepts for which practicing engineers had relatively few misconceptions and those for which they had several. Concepts with low practicing engineer misconception rates include coordinated signals, yellow change intervals, actuated signals, vehicle detection, and phases. These concepts are all an explicit part of the traffic signal design process. Coordinated and actuated signals are classifications of intersection types, and the determination of intersection type is one of the first decisions that a traffic engineer needs to make when considering how to signalize an unsignalized intersection. When developing the timing plan for a signalized intersection, traffic engineers are required to make frequent decisions regarding phasing and the duration of yellow change intervals. In contrast, the concepts where practicing engineers had relatively high rates of misconceptions (minimum green time and passage time) are fundamental timing processes that are embedded in analysis, software, and guidebooks as mentioned in the results section. By embedded it is meant that practicing engineers can generate values for these parameters by applying equations, software, or guidebooks without a deeper understanding of the limitations of the procedures or the fundamental importance of the parameters.

This comparison begs the question of what should be done in terms of preparing students to be practicing engineers in transportation engineering courses. Should the embedded concepts be left out or only minimally covered? Most educators would be concerned with this approach. The authors suggest that a research-based curricular approach would be a first step toward better understanding core traffic signal concepts. If the concepts are embedded in practice, they should be presented as such in the curriculum (i.e., in an authentic context). Direct data from interviews should be used to represent this authentic knowledge. The next section provides two examples with a description of how the data were used to develop the exercises.

DATA-DRIVEN CURRICULUM DEVELOPMENT

For the purpose of demonstrating how clinical interview data, and in particular the identified misconceptions, can be applied to improve traffic signal education, a series of conceptual questions were developed to help students and young practitioners to better understand traffic signal fundamentals and to help educators better teach those principals. When using interview data to construct conceptual exercises, it is important to correctly select meaningful student misconceptions. Misconceptions in this sense are not just wrong answers, they are wrong answers founded in strong student reasoning, and are traditionally difficult to correct even when students are presented with contradictory evidence. Examples of a concept inventory question and a ranking task (Figure 2) are considered in the following sections.

Concept Inventory Questions

One type of conceptual exercise is a concept inventory question. Concept inventory questions are multiple-choice questions with one correct answer and three to four incorrect distractors. Distractors are misconceptions that are determined from research on student and practitioner understanding through interviews and pilot testing. Below is an example concept inventory question about the red clearance interval developed to address a misconception that the duration of red clearance interval varies with traffic volume at the intersection that was pervasive among all three cohorts. All the wrong answers were drawn from misconceptions that were found through the student and practitioner clinical interviews:

Which of the following statements most accurately describes the relation between the red clearance interval and the traffic volume at an intersection?

A. Only the volume of the major street influences the duration of the red clearance interval.
B. Only the volume on the active approach influences the duration of the red clearance interval.
C. Traffic volume is not directly related to the duration of the red clearance interval.
D. Higher traffic volumes result in longer red clearance intervals.
E. The duration of red clearance interval is inversely related to intersection traffic volumes.

The correct response to this question is C, "Traffic volume is not directly related to the duration of the red clearance interval." This type of question can be used both as a formative and summative measure of student understanding.

Ranking Tasks

Ranking tasks constitute another category of conceptual exercise. In a ranking task (Figure 2) students are asked to order a sequence of typically three to six items on the basis of a particular characteristic. Often the items are pictures or figures and the task is intended to be completed without the use of calculations. The task can be made more difficult by including extraneous information and presenting the items in a variety of contexts. A ranking task deals with the same content as the concept inventory question, the misconception that the volume of conflicting vehicles is related to the duration of the red clearance interval.

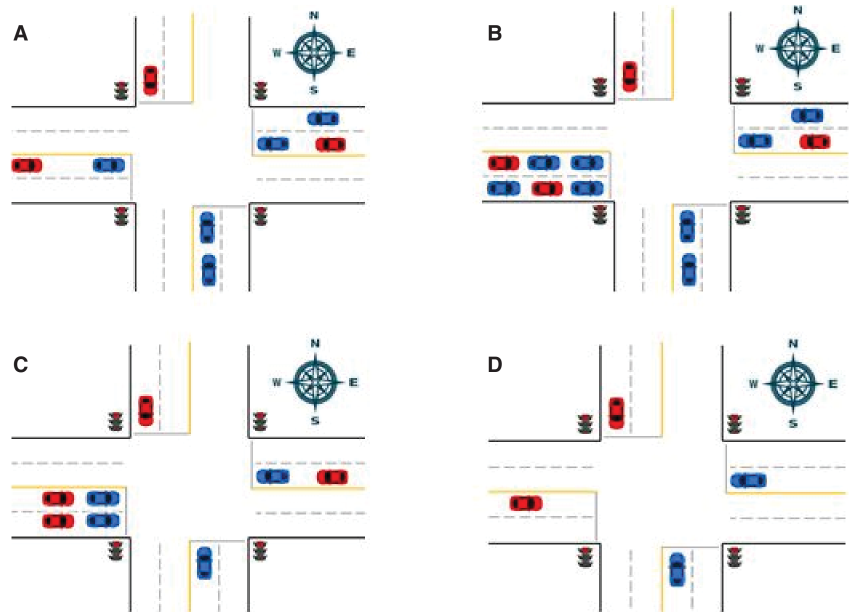
The correct response to this question is that the red clearance interval should be the same for all four intersections. Traffic volume is not directly related to the duration of the red clearance interval. Questions of this type can be used both as a formative and summative measure of student understanding.

CONCLUSIONS

Advancing understanding of the knowledge of experts and novices in engineering is important for both theoretical and practical reasons. Theoretically, these findings provide the first evidence that practicing engineers also have misconceptions and that these particular concepts may be embedded in practice, perhaps not requiring explicit knowledge on a day-to-day basis by practicing engineers. Participants answered questions in terms of their context and previous experience (e.g., students and minimum green time, or practicing engineers and reference manuals), suggesting that to some extent their knowledge is embedded in or related to a particular context. The cognitive–situational divide has not been solved, but progress has been made in understanding how largely different cohorts relate to particular concepts. Practically this has implications for student preparation. Suggesting curriculum based on direct results from clinical interviews is the first step. This curriculum must be tested with students to evaluate the effectiveness in understanding its impact on preparing students for the workforce. It is likely that representing knowledge cannot be

The following figures show typical four-leg signalized intersections with different traffic volumes.

Rank the figures based on the duration of the red clearance interval (all-red time) required for the eastbound traffic signal phase before displaying green to the north–south direction of traffic, from the longest to the shortest. Assume identical lane configuration and intersection geometry in all four cases, and 35-mph posted speed limit on all four approaches and the same design vehicle at each intersection.



Longest ________ ________ ________ ________ Shortest

Or the red clearance interval should be same for all of these. _________

Or the information is not adequate to determine the red clearance interval _________

How sure were you of your ranking? (Circle one.)

Basically Guessed Sure Very Sure

1 2 3 4 5 6 7 8 9 10

FIGURE 2 Example ranking task.

accomplished completely in a paper-based curriculum but may require facilitating either synchronous or asynchronous interactions between students, faculty, and practicing engineers.

This research is a first step in identifying misconceptions in novice and expert students and practicing engineers, and in considering what these individuals relate their knowledge to. The results can be used as an attempt to bridge the gap between academia and the workplace. To make further progress, future research is necessary at multiple steps along the continuum for fundamental research to classroom implementation. Future research is needed to explicitly test the effectiveness of curriculum development that attempts to authenticate curriculum. Does this curriculum result in fewer misconceptions? Do engineers result who have better situated knowledge, but less conceptual knowledge. Better preparation of engineers has the potential to positively influence the safety and efficiency of signalized intersections currently in the planning, design, or operations phase of development.

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