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Mental Models of Students and Practitioners in the Development of an Authentic Assessment Instrument for Traffic Signal Engineering

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Abstract

Conducting fundamental engineering education research on student and practitioner ways of knowing is a critical and often overlooked first step in curriculum and assessment design. This research project determined the core concepts related to and synthesized student and practitioner conceptual understanding of isolated and coordinated signal systems. A modified version of the Delphi Method was used to develop consensus among 16 transportation engineering faculty and engineering professionals on the most consistent, relevant, and core concepts in traffic signals. The most important concepts are warrant analysis (or determining the need or justification for a new signalized intersection) and signal timing, calculations, and phasing. Clinical interviews were conducted with approximately 50 students and 35 early career engineering professionals to investigate, characterize and synthesize their understandings of traffic signal operations. Comparison of understandings are in process to determine differences in how engineering students and early career engineering professionals think about signal design and to determine persistent misconceptions within this discipline. Additionally, interviews are being analyzed to determine common misconceptions. This research will produce a taxonomy of differences in the knowledge of students and early career engineering professionals related to traffic signals and a summary of misconceptions. These project outcomes will be the basis of a newly-developed concept inventory and curriculum, such as inquiry based conceptual exercises and assessments, both of which will be situated in authentic engineering thinking and design. This study is significant because it fundamentally advances the field by identifying differences in conceptual understanding between practicing engineers and students with respect to the design and operation of traffic signal systems. Traffic signals are a central component of transportation infrastructure as they directly contribute to the safety and efficiency of the surface transportation system.

Project Introduction

A large body of research has shown that many graduating students do not possess an understanding of fundamental concepts in fields such as physics [1], mathematics [2] and engineering [3]. Confounding the lack of conceptual understanding are differences between how academics and engineering professionals think about and apply fundamental engineering concepts. Situated cognition experts contend that knowledge only exists in context and has very limited meaning and usefulness when taught out of context [4, 5]. An *urgent educational need* exists to better integrate engineering students within the context of engineering practice and to develop, implement, and assess curricular materials that represent this integration, including high quality assessment instruments. No concept inventory instruments currently exist in transportation engineering, and no existing engineering concept inventory (CI) instruments have been validated in engineering practice. The lack of situated or contextual curricular materials integrating conceptual understanding and practice impedes students' abilities to be productive and innovative engineers.

Project Goals, Objectives, and Specific Aims

The *objective* of this research effort is to synthesize early career engineering professionals' and students' ways of knowing traffic signals and use this knowledge to develop a concept inventory in traffic signal operations that is relevant to engineering practice. The *rationale* for the work was that conducting fundamental engineering education research on student and practitioner ways of knowing is a critical and often overlooked first step in curriculum and assessment design and having an engineering design relevant traffic signal operations concept inventory (TSCI) will provide explicit evidence of what is important for students to know, how much they know about these important concepts, and how and where to focus transportation engineering design courses.

The *specific aims* of the Research Plan included the following elements:

I. **Determine core concepts for isolated, coordinated, and systems of traffic signals**. A modified version of the Delphi Method was utilized to develop consensus among transportation engineering faculty and engineering professionals on the most consistent, relevant, and core concepts in traffic signals. The modified method incorporated both anonymous and collaborative practices.

II. **Synthesize student and practitioner conceptual understanding of isolated, coordinated, and systems of traffic signals.** Validated clinical demonstration interviews were conducted with approximately 30 students and 25 early career engineering professionals, (15 students each from Washington State University (WSU) and Oregon State University (OSU)) to investigate, characterize and synthesize their understandings of traffic signal operations. Comparison of understandings were conducted to determine differences in how engineering students and early career engineering professionals think about signal design and to determine persistent misconceptions within this discipline.

III. **Develop a situated concept inventory for isolated, coordinated, and systems of traffic signal.** The TSCI will be developed based on interview and concept prioritization results, assessment and misconceptions theory and established protocols for CI development.

IV. **Implement TSCI at 12 Universities throughout the US and Disseminate Research Results.** The TSCI will be implemented in undergraduate and graduate transportation engineering courses at a minimum of 12 universities across the country, resulting in a large data set to test the validity and reliability of the instrument. Engineering faculty at these 12 universities have already committed as early adopters, but it is expected that additional institutions will be identified.

Current/Past Activities

In alignment with the three foundations of quality assessment, the steps for creating a TSCI are listed below [6]. These steps may be iterative, depending on the complexity of the subject matter and the success of the initially developed TSCI.

1) Determine concepts to be included
The fundamental concepts of traffic signal operations were identified through an iterative modified Delphi process involving 14 senior engineering professionals and 16 engineering faculty from across the country. The academics both teach and do research in the area of traffic signal operations, and the senior engineering professionals have worked in the design, construction, analysis, or optimization of these types of facilities. Determination of fundamental concepts included the individual development of a list of core concepts, and a webinar to discuss and debate and build consensus on the final concepts. These experts were compensated for their time.

2) Study and articulate the learning process regarding these concepts
Focused interviews with approximately 25 students each from WSU and OSU, and 35 early career engineering professionals from the area surrounding each university were used to investigate conceptual understanding, determine misconceptions related to the key concepts chosen, and develop mental models that represent these understandings.

Planned Activities

3) Construct several multiple choice questions for each concept
Strengthened with the final list of concepts developed as a direct result of consensus building between our engineering faculty and senior engineering professionals in Specific Aim 1 a preliminary set of 3 multiple choice questions will be proposed for each fundamental concept resulting in approximately 24 to 30 questions. The process will be iterative in nature. Initially a webinar will be held where a draft of several questions will be proposed and contributed to as a group. After the initial webinar each engineering faculty member and senior engineering professional will continue to advance the questions independently. A final webinar will be held where a final consensus will be reached regarding the form of each question.

4) Administer the beta version of the inventory to as many students as possible and perform statistical analyses
In order to confirm that the developed TSCI is of marked predictive value it is critical to validate the tool. The inventory will be validated through two general approaches; test-retest reliability and item analysis. Test-retest reliability will determine if scores are consistent across different randomly selected portions of the exam. The item analysis will help determine if individual distracters are valid or not based on the frequency they are selected. The test-retest reliability of the TSCI will be determined by administering the exam to the same set of student respondents during two different times. To minimize the potential for a "practice effect" the inventories will be given at least one month apart. Additionally, to avoid learning effects, the TSCI will not be given during the same time modules dealing with traffic signal operations are being taught. A high degree of reliability would result from the test scores being approximately the same for both test times. The correlation coefficient is commonly used to compare the degree of linear relationship between two variables, and will serve as the statistical measure for our test-retest reliability.

Project Findings/Status

We have determined the focus concepts for this project using a modified Delphi process with the involvement of about 15 practicing transportation engineers and transportation engineering faculty. The concepts are warrant analysis (or determining the need or justification for a new signalized intersection) and signal timing, calculations, and phasing. With these concepts in mind we developed, including an extensive testing and piloting phase, interview protocols for novices and experts. Although the concepts were the same the novice protocol needs to be different to avoid confusing jargon and advanced concepts. We have also conducted about 30 student interviews and 25 practitioner interviews and are in the process of analyzing these interviews. We expect to have a draft set of questions complete by the end of May 2013.

Project Outcomes

The expected outcomes of our research efforts are a prioritized list of concepts of traffic signal operations that engineering faculty and senior engineering professionals believe are important; a synthesis of student and early career engineering professionals' understandings of traffic signals, resulting in a draft set of distracters for each TSCI question; a taxonomy of differences in knowledge of students and early career engineering professionals related to traffic signals; national dissemination of a valid and reliable traffic signal operations CI and research results on engineering students and early career engineering professionals' understandings of traffic signal systems; a database of student performance on the TSCI in the classroom, and a framework for developing situated concept inventories. This study is creative and original in that it represents the first-ever meaningful integration of engineering professionals into the assessment of student's conceptual understanding and related curriculum development.

Significance of Findings

Concept inventories in transportation engineering, and more specifically traffic signal engineering do not exist (of the 16 engineering faculty who have committed to participating in this research effort none have ever encountered a CI in any area of transportation engineering. Concept Inventory Central is a clearinghouse of all known SME Concept Inventories supported at Purdue University. This resource shows no evidence of a CI in any area of transportation engineering.) *This study is significant because it fundamentally advances the field by identifying differences in conceptual understanding between practicing engineers and students and develops a concept inventory instrument incorporating practitioner understandings.* Data collected from practicing engineers and students can be used for several vital purposes in addition to the CI development efforts planned as part of this proposal. These include curriculum development, such as inquiry based conceptual exercises [7, 8] and assessments that complement CI questions, such as open-ended design problems, both of which will be situated in engineering thinking and design. The methodologies developed can be applied to the development of future engineering concept inventories situated in engineering practice.

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