Assessment of Students' Preconceptions in the Introductory Transportation Engineering Course: Case Study at Virginia Tech

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ABSTRACT

Introductory transportation engineering (TE) courses are crucial for developing students' interest in TE, and for creating professional knowledge foundation. However, effective learning requires certain conditions. Students' preconceptions are instrumental to the learning process, and ignoring preconceptions can result in creation of knowledge gaps and negative effects on learning. The previous research did not focused on students' preconceptions in the introductory TE courses. Consequently, the purpose of this case study was assessment of students' preconceptions in the introductory TE course at Virginia Tech. The research methodology was based on a pre-course survey and concept maps, including a development of transferable coding method. Qualitative data was used to assess how students integrate, organize and relate concepts using their previous knowledge. Results indicate that variation of students' preconceptions exists based on their major and year, along with specific positive, negative or incomplete concepts. Additionally, the analysis indicates increase in concept consistency and convergence in concepts based on students' previous knowledge. Conclusively, awareness of students' preconceptions is necessary for developing new approaches that could improve the learning environment.

Key words: Transportation Engineering Education, Preconceptions, Concept map, Student survey

INTRODUCTION

In the next decade, transportation engineering (TE) profession will face a noticeable brain drain due to significant retirements accompanied with higher labor demands ("Creating Sustainable Human Capital Investment," 2012; "National Transportation Workforce Development," 2015; Norman, 2010; "Special Report 275: The Workforce Challenge - Recruiting, Training, and Retaining Qualified Workers for Transportation and Transit Agencies.," 2003; Wolch, 2011). In addition to this brain drain, the evolution of 21st century transportation systems will impose higher requirements on the profession. Furthermore, additional criteria from the Accreditation Board for Engineering and Technology (ABET) catalyze the requirements for educating future transportation engineers ((ASCE), 2008; Corotis & Scanlan, 1989; "Criteria for Accrediting Engineering Programs - Effective for reviews during the 2013-2014 accreditation cycle," 2012; Eck, 1990; Yean Yng Ling, Khai Ng, & Leung, 2011; Zheng, Shih, Lozano, & Mo, 2011). Consequently, there is a critical need for attracting more and academically highly competent students into the TE field (Agrawal & Dill, 2008; Ivey, Golias, Palazolo, Edwards, & Thomas, 2012; Mintz, Talesnick, Amadei, & Tal, 2014).

Higher requirements in the profession impose the need for improved TE education. Positive highlights from the current education practice tell us that at least one TE course is offered in over 90% of undergraduate programs in civil engineering (CE) (Rod E Turochy, 2013 ; Wolch, 2011). Despite this presence of TE courses, the dominant practice is to have only one or two undergraduate courses in transportation, while majority of the coursework is concentrated in the graduate level (Russell & Stouffer, 2005; Sinha et al., 2002). Considering a limited number of undergraduate TE courses, introductory TE courses are crucial for developing students' interest in pursuing a career in TE (Agrawal & Dill, 2008; Rod E. Turochy et al., 2013). In addition, introductory TE courses are important for providing foundational knowledge, as a first step towards pursuing higher-level courses or professional career in TE.

Apart from the importance of the introductory courses, one needs to remember that learning does not happen under any condition (Crain, 2005; Jarvis, 2006). There is a fundamental need for a context-dependent and situated learning environment if we want learning to occur (J. S. Brown, 1989; Davis, Brown, Dixon, Borden, & Montfort, 2013 ; Lave & Wenger, 1991; Pellegrino, Chudowsky, & Glaser, 2001; Robbins & Aydede, 2009). Students are one of the most important elements of the learning environment. Students as individuals enter education with a range of prior knowledge, skills, beliefs, and concepts formed through years of learning and interaction with everyday experiences (S. Brown, Nicholas, & Kyte, 2013; Jewers et al., 2010). Consequently, because learning occurs in a context, these preconceptions affect student's abilities to reason and acquire new knowledge (*How People Learn: Brain, Mind, Experience, and School*, 2000). Moreover, some students find it troublesome to understand and express a particular idea or concept if a misconception exists (Davis et al., 2013 ; Male & Baillie, 2011; Meyer & Land, 2003; Perkins, 1999). Taking into consideration these effects stemming from preconceptions, one can conclude that it is of high importance to consider them for transformative learning experience to happen.

Research Objectives

Previous research efforts for improving TE education focused primarily on development of new teaching and learning tools using the Information and Communication Technology (Bertini, Monsere, Byrd, Rose, & El-Seoud, 2005; S. Brown et al., 2013; Chen & Levinson, 2006; Liao & Levinson, 2013; Liao, Liu, & Levinson, 2009; Liao, Morris, & Donath, 2006; Lorion, Harvey, & Chow, 2014; Rodrigues Da Silva, Kuri, & Casale, 2012; Rose, 2011; Zhu, Xie, & Levinson, 2011). Furthermore, previous research has also discussed improved teaching practices, in-class activities, curriculum redesign, and course development (Handy, Weston, Song, Lane, & Terry, 2002; Huang & Levinson, 2012; Hurwitz et al., 2014; Khisty, 1996; Kyte, Abdel-Rahim, & Lines, 2003; Mladenovic, Mangaroska, & Abbas, 2014; Pitera & Goodchild, 2014; Rod E Turochy, 2013). However, there is limited previous research that observed and explored learners' preconceptions in TE. One example is in a traffic signal control course (Cooley, Brown, & Abdel-Rahim, 2012). In this research, students' preconceptions were assessed using a knowledge survey. The preconceptions were related to the knowledge gained in the introductory TE course and students' experience as transportation users. In addition, there were several studies where conceptual understanding was assessed, including a traffic systems design course (S. Brown et al., 2013), and a transportation planning course (Prado da Silva, Fontenele, & Rodrigues Da Silva, 2014).

Contrary to the previous research, the case study presented here focuses on students' preconceptions in the introductory TE course. The following case study is a study with limitations, which are discussed at the end of the paper. Considering the aforementioned importance of introductory TE course and the impact of preconceptions on learning, the main purpose of this study is to explain the methodology used for assessment of students' preconceptions. Moreover, in order to point out the importance of students' preconceptions in the learning process, this study addressed the following questions:

1. What are students' preconceptions before entering introductory TE course?
2. How do the preconceptions vary based on student's background?
3. How are preconceptions modified based on the course curriculum?

DESCRIPTION OF LEARNING ENVIRONMENT

As mentioned in the previous section, learning does not happen under any condition but is rather dependent on the learning environment. The type of learning environment, its elements, and interaction between these elements have a great effect on student learning and knowledge construction. Moreover, students respond differently to diverse teaching practices and pedagogical innovations (Rodrigues Da Silva et al., 2012). With respect to this, it is important to understand thoroughly the learning environment for situating the student learning and knowledge construction, and customizing the assessment process.

The course that was under assessment in this case study is CEE 3604 Introduction to Transportation Engineering (CEE 3604) at Virginia Tech, taught during spring 2013. The course includes aspects of transportation planning (e.g., estimation of flows on transportation networks over time), transportation design (e.g., design of specific roadway curve parameters) and transportation operations (e.g., traffic-signal timing optimization). The course objectives, reordered to structure course curriculum, are as follows:

1. Model vehicle acceleration and deceleration behavior and estimate the distance required to accelerate and decelerate.
2. Forecast traffic volumes for the design of transportation facilities using Travel Demand Modeling.
3. Estimate different traffic stream parameters (flow, density, and speed) and estimate queues at roadway bottlenecks.
4. Estimate freeway, multi-lane highway, and two-way highway level of service.
5. Design and evaluate traffic signal timing parameters.
6. Design the geometric vertical and horizontal alignment of highways.
7. Design flexible and rigid pavements using the AASHTO procedures.

Furthermore, the course is organized around the book "Principles of Highway Engineering and Traffic Analysis – Fifth Edition" by Fred Mannering and Scott Washburn. The textbook is selected as an entry-level transportation-engineering book. The course is mapped to ABET criteria a) through j), not including only criteria k) ("Criteria for Accrediting Engineering Programs - Effective for reviews during the 2013-2014 accreditation cycle," 2012).

In addition to course information, a general teaching-goal inventory was developed for this class using an online assessment tool (Angelo & Cross, 1993). The instructor assessed each goal importance in accordance with the expectation on students rather than the goal's general worthiness. The goal's importance was assessed using an ordinal scale, ranging from goal you never try to achieve (not applicable) to goal you always/nearly always try to achieve (essential). The following Table 1 presents the results. The first column shows which goals are included in each cluster. The complete list of goals is presented online at (Angelo & Cross, 1993). The second column shows the percentage of goals within each cluster that are rated "essential". At the end, the third column shows the average rating assigned to goals within each cluster.

Table 1.

The course is open for undergraduate students majoring in Civil and Environmental Engineering (CEE), Construction Engineering and Management (CEM), Industrial and Systems Engineering (ISE), and Mechanical Engineering (ME). The course is part of required curriculum only for the students majoring in CE, while it is an elective course for the rest of the students. Conclusively, CEE 3604 is a course concentrated on road TE, aiming at a wide range of ABET student learning outcomes. In addition, CEE 3604 focuses on discipline-specific knowledge and higher-order thinking. Finally, the course had a diverse learning environment, with students entering from different engineering fields and different knowledge base.

METHODOLOGY

Pre-course survey

Considering the starting assumption that preconceptions affect learning process, the first part of this case study was an anonymous survey that was conducted before the beginning of the course. Although 38 students enrolled in the course, only 31 have participated in the pre-course survey. Table 2 below presents a compiled list of answers to three questions directly related to this study. Table 2 does not contain all of the answers, only the ones that differ from the majority of the provided answers. This way the selected sample will easily show the preconceptions that originate from students' previous education and experiences. Because majority of the students in this course are from ISE, most of them (79%) answered that they had selected this course as a technical elective course that was somewhat interesting to them. Six students answered differently to the first question and those answers are shown in Table 2. As one can observe, these answers confirm that some of the students had previous experience with transportation topics. The answers to the question on the learning expectations from the course were twofold. On one hand, 56% of the students wanted to learn generally about TE and its relation to society. On the other hand, 20% of the students were interested in learning about specific areas, e.g., traffic management, queuing theory or road design. Such answers implied that some students had preconceptions about transportation systems and infrastructure. Furthermore, the answers to the question on relation with previous courses provided a wide range of courses students considered relative to CEE 3604. CEE and CEM students primarily related CEE 3604 to Building Materials and Environmental Engineering. In addition, it was interesting to see how ME students related CEE 3604 to Fluid, Vehicle or System Dynamics courses, while ISE students related it to Operations Research, Management and Simulation courses. The information from this table supports the premise that students are entering the course with preconceptions that can shape the way they learn concepts in TE. Finally, information from Table 2 supports the premise that these students enter CEE 3604 with different knowledge base, depending on their major. In addition, 95% of the students have a driving license, thus entering the course with definite previous experience as transportation users.

Table 2.

Concept Maps as Preconception Assessment Tools

The main part of the case study used concept maps as tools for assessing students' preconceptions. Concept maps are defined as "graphical tools for organizing and representing knowledge" (J. D. Novak & Cañas, 2008). As a pedagogical tool for evaluation of learning, concept maps have been proposed by John Novak in the 1970s based on the theory of meaningful learning (J. Novak & Gowin, 1984; J. D. Novak & Cañas, 2008). Typical concept map consists of circles or boxes containing concepts (usually using nouns), connected by directed lines that show the relationships between those concepts (usually using verbs). Concept maps are frequently used to make abstract concepts more tangible, answer a specific question, encourage higher-order thinking skills, increase understanding and as a method for measuring students' conceptual knowledge (Besterfield-Sacre, Gerchak, Lyons, Shuman, & Wolfe, 2004; J. Novak, 1990; Vekiri, 2002). One important feature of concept maps is that it forces students to challenge their own understanding, while having flexibility to present differences in thinking.

In this case study, the research team decided to use concept maps to evaluate how accurately students integrate the concepts they present in the map, how they organize and relate the concepts about TE based on their preconceptions, and how well they reflect an understanding of TE activities. The participation in the study was voluntary, without exclusion criteria. The study was presented as an in-class activity in which interested students signed a consent form for participation, and approved that their assignments can be used for the needs of this research. Any risk was excluded, since concept maps were coded and evaluated after the semester was over and final grades were assigned.

There were two individual assignments in the form of a concept map, each developed in 30 minutes during class time. The beginning-of-semester concept map (BCM) was assigned during the first class, right after students' introduction, without presenting any information regarding TE (examples are presented in Figure 2 and Figure 3). The BCM objective was to find out what kind of understanding students have about TE based on their previous engineering education and experience as transportation users. The end-of-semester concept map (ECM) was assigned after ending all the lectures and assignments, and before the last class in the semester (example is presented in Figure 5). The purpose of the second assignment was to assess the evolution in the student understanding regarding TE after taking the class. The total number of participants in this case study was 38, with 36 having done BCM assignment and 30 ECM assignment. From this number, seven students were from CEE, one from CEM, 24 from ISE, and six from ME. The course distribution was one sophomore, eight junior (mainly majoring in Civil Engineering), and 29 senior students (mainly majoring in ISE and ME). Gender distribution was 33 males and five females.

Great majority of the students in this study had never developed a concept map before, and therefore concept mapping was presented to them as an assignment with accompanying explanation as shown in Figure 1. The explanation of the concept map assignment was divided into three sections. The first section introduced a concept map as a visualization tool along with its features. In the second section, students were given step-by-step instructions how to create concept maps (the left side of Figure 1). At this point in time, the instructor explained that TE is the core concept and a starting point for the concept map development. In the last section, an example figure of concept map was presented, depicting the term "scientific method" (the right side of Figure 1).

Figure 1.

Figure 2 below presents examples of BCM from two students majoring in CEE and CEM, respectively. In addition, Figure 3 presents examples of BCM from two students majoring in ISE and ME, respectively. Here, one can immediately see the benefit of using concept maps, which is a visual representation of the concepts and their inter-relations. From a brief observation of the concept maps presented in Figure 2, one can readily observe similarities and differences in preconceptions between CEE and CEM students. Both students saw a close relation between TE, economy, and infrastructure. In addition, they have identified the importance of safety as a goal of TE activities. On the other hand, observing the concept maps presented in Figure 3, one can easily notice differences among ME and ISE students, both between them, and comparing to CEE/CEM students. The ME student included an important concept of vehicles. In addition, it is interesting to perceive that the same student incorporated railways as a concept related to infrastructure. In comparison, an ISE student has placed great emphasis on data analysis. Furthermore, it is interesting to observe how the same student preconceived logistics as part of TE, establishing a relation to several transportation modes. Consequently, from just a brief look at these four concept maps, one can see that students enter CEE 3604 with a wide range of preconceptions about TE. As a result, concept maps gathered from all of the students allowed us to establish an overview of students' preconceptions, while remaining a tool for developing individual learning goals. Therefore, in order to evaluate quantitatively all the concept maps in this study, the research team has devised a coding procedure, presented in the next section.

Figure 2.

Figure 3.

Methodology for Coding Concept Maps

The methodology for analytical assessment of concept maps draws from the field of linguistics, integrating the development of an evaluation method with analysis performed in semiotics. According to its definition, semiotics is the study of signs and their use or interpretation (Laferrière, 1977), or in other words, the study of meaning-making. Semiotic analysis includes lexical semantics, which studies the meaning of words and relations between them. Semantic analysis incorporates the hyponymy and meronymy relations among concepts (Murphy, 2003). In linguistics, a hyponym is a word or a phrase that represents a more specific instance of a more general term (hypernym). For example, rail or road transport are all hyponyms of land transport (their hypernym); which, in turn, is a hyponym of transport mode. On the other hand, a meronymy (the part-whole relationship) is a semantic relation that denotes a constituent part of, or a member of something. For example, an articulated bus is meronym of public transport vehicle (holonym). Investigation of semantic relations between concepts in TE has been a focus of previous research (Popescu, 2010). Development of coding parameters based on the semantic analysis is embedded into an assessment rubric. Finally, an example at the end of this section depicts the suggested methodology for coding concept maps.

As a result of the suggested semiotic analysis, the analytical coding of concept maps integrates two parameters, named relatedness and connectedness. Relatedness investigates the relation between the concept and the core concept, determining how closely each concept is associated with the core concept. This association is determined on the scale from one to five, aiming to determine if a student has general understanding which concepts are part of TE. Association between the concept and core concept (TE) is evaluated based on the definition of TE and a sample of more specific concepts. For the purpose of evaluating relatedness, the core concept definition of TE is derived from (*Traffic Engineering Handbook*, 2009), as "the application of technology and scientific principles to the planning, design, operation, maintenance and management of systems and facilities for any mode of transportation (highway, rail, air, water, and pipeline) in order to provide for the safe, rapid, comfortable, convenient, economical and environmentally compatible movement of people and goods". In addition to the previous definition, examples of specific concepts were deduced from the broad definition of TE, shown in Figure 4. The sample of specific concepts was created in alignment with the course objectives and the developed general teaching-goal inventory. This sample of concepts is a supporting coding element to the definition of the core concept. An example of highly related concept is 'traffic signal control', as the core TE area, while an example of unrelated concept is ‘soil’, as a term more relevant for other civil engineering areas. It is important to note that every instructor has the liberty to choose her own examples of specific concepts based on the course objectives and the course teaching-goal inventory.

Figure 4.

In addition to determining the relation to the core concept, concept map coding needs to evaluate relations among the concepts themselves, and their logical sequence of part-whole relations. Logically sequenced and connected concepts within the concept map show student’s in-depth understanding of the material. This is the reason why, besides relatedness, this methodology introduces connectedness. Connectedness measures the level of clarity in the logical flow between the neighboring concepts, and is also evaluated on the scale from one to five. An example of a well-connected concept is a concept that has several other neighboring concepts, logically connected with links that preferably contain verbs. Previous concept ‘articulated bus’ connected to ‘public transport vehicle’ concept with a directed arrow containing a verb ‘includes’ is an example of a well-connected concept.

Besides the relatedness and connectedness, which assess the semantic relations in the concept map, another parameter, concept level, was introduced. The concept level determines the relative spatial position each concept has in relation to the core of the concept map. Depending on the spatial position in relation to the core concept, concepts can be primary, secondary, or tertiary. Concept level represents conversion or diversion of concepts around a central concept, i.e. the complexity and scale of the concept map observed in space. A well-developed concept map should have many tertiary concepts, as it presumes that a student can think in layers of knowledge, and has a certain depth of understanding. It is important to note that coding of concept level needs to start from the core concept towards the edge of the concept map, starting with determining primary concepts.

The aggregation of all three parameters that each concept has, describes the depth of concept map development, the relation to the core concept of TE, and the connections between the neighboring concepts.

Taking into consideration these established parameters, the research team developed an assessment rubric (Bartels, 1995; "Grading and Performance Rubrics," 2015; "Rubric for Assessing Concept Maps," 2015). The assessment rubric contains explicit and descriptive set of criteria for coding the concept map. The proposed criteria are used to ensure uniformity in the process of coding the concept maps. Table 3 shows the assessment rubric created using an ordinal scale from one to five for relatedness and connectedness, and from one to three, for concept level.

Table 3.

Figure 5 shows a coded example of ECM with the parameters presented in brackets on the upper right side, as [level, relatedness, and connectedness]. The core concept “Transportation Engineering” is placed in the left central side of the concept map. For example, a concept “Traffic Analysis” is coded as [1, 5, 5]. This concept is coded as primary since it is very close to the core concept. Furthermore, it is an important concept directly related to the definition of TE thus indicating a strong relation with the core concept. In addition, the concept denotes a clear terminology and strong understanding of the core concept. Connections to and from the concept indicate superior organization and enhance meaning in the context of TE. The concept is interlinked with several other concepts and show a superior level of clarity in the logical sequence of part-whole relations with the neighboring concepts. Finally, the context in which this concept is placed contributes greatly to the meaning of the core concept. As for the right side of the concept map, a concept “Aerodynamics” is coded as [3, 3, 3]. This concept is coded as tertiary, since it is far away from the core concept. Furthermore, the concept is more related to ME rather than to TE. Therefore, one can observe that the concept denotes a clear terminology but shows some misunderstanding of the core concept. Moreover, the concept has a fair relation to TE and only one connection with another concept. Finally, this concept does not demonstrate a meaningful meronymy relation and its context somewhat contributes to the meaning of the core concept.

Figure 5.

ASSESSMENT RESULTS

After coding the concepts from the concept maps, the research team performed a qualitative analysis. The software used in this case study for qualitative analysis of concept maps was NVivo ("NVivo,"). This software enabled search and query analysis necessary to process the coded information.

General Analysis of Concepts

Starting with an overall analysis, the following Table 4 presents a list and frequency (freq.) of the most recurrent words found in BCM and ECM. With respect to this, one can get the idea of how these students perceived TE before entering the course. From Table 4, one can observe that students frequently used concepts related to road transportation (e.g., roads, highways, cars, vehicles), and infrastructure design and construction. Besides road transportation, students had a strong preconception about relation between air transportation and TE (e.g., air, airports). Furthermore, students recognized the relation between TE and traffic flow, and between TE and safety. Finally, up to a point, students had some preconception about public transportation. In comparison, observing the other most frequently used words in BCM, one can see that they are related to general engineering concepts. One potential explanation of the concept frequency might be a dominant engineering knowledge base that all the students have, considering all the students were from engineering majors.

Observing the column Difference from Table 4, one can see the values that represent the relative difference in the word frequency between BCM and ECM. The relative difference is measured with respect to concepts from the BCM. For example, the concept “roads” has been used 34 times in BCM, and only 24 in ECM, thus resulting in the difference of 10 shown in the middle column. In addition, the numbers shown in the column Difference indicates the change. If the value is a positive number, the word is more frequently mentioned in BCM, rather than if the value is a negative number, when the word is more frequently mentioned in ECM. As one can observe, middle column shows that words “traffic”, “design”, “flow”, “highway”, “safety”, and “vehicles” are more frequently mentioned in ECM than in BCM. With this in mind, one can notice that there is a change in students’ preconceptions regarding these concepts, considering them more related to TE. Furthermore, observing the concepts in the ECM columns, one can conclude that they are not as general as they were in BCM column, but that they are more closely related to TE. Finally, the research team has noted a difference in the maximum, minimum, and average number of concepts in BCM and ECM. Maximum number of concepts in BCM was 21, minimum was 6, and average 14.6. On the other hand, maximum number of concepts in ECM was 42, minimum was 7, and average was 21.2. The difference between values obtained from BCM and ECM signifies an increase in the number of concepts used.

Despite this general representation of concepts in Table 4, the research team has also focused on the analysis of concepts depending on students major, presented in Table 5. The student from CEM was grouped with students from CEE, due to the similarity of majors, in comparison to ISE or ME. From Table 5, one can observe that students from CEE/CEM relate the core concept primarily to construction and infrastructure, while students from ME to air transportation. In addition, both groups of students had preconceptions related to safety, potentially originating from their perspective as users. Moreover, students from ISE had strong preconceptions about several concepts, including traffic flow, logistics, data and data analytics (minimize, maximize), time, and queues. Each of these preconceptions is logical, considering the previous coursework these students had.

Table 4.

Table 5.

The lower part of Table 5 shows the most frequent concepts that students had at the end of the semester, based on their major. These concepts confirm how students' knowledge has been modified on the basis of their preconceptions at the beginning of the course. Overall, as in Table 4, concepts are more specific to TE, but depend on the student's major. One can observe that the preconceptions CEE/CEM students had in relation to construction had now evolved in relation to road and pavement design. By contrast, ISE students maintained some of their preconceptions related to flow and queuing theory, although their conceptions have evolved too. However, it is important to observe a significant increase in consistency of keywords (words shown in bold) from BCM to ECM. Finally, all students have greatly strengthened their understanding of relation between TE and design.

Table 6 below presents students concepts from BCM and ECM, based on students' year. Observing the left side of Table 6, with BCM concepts, one can conclude that senior students had preconceptions related to general engineering activities (e.g., design, minimize, limited, engineering, maximize, planning, etc.). By comparison, sophomore and junior students had preconceptions related to TE primarily as transportation users (e.g., management, population, bridges, cars, people, goods, etc.). The right side of this table depicts how the concepts between senior and junior students have changed after the course. One can observe that senior students have maintained their established engineering perspective on TE, which has evolved into corresponding TE concepts related to infrastructure or systems. However, although junior students have modified their concepts (e.g., "design" is a second most frequent factor), they have still maintained some of their previous perspective on TE from the role of transportation users (e.g., population, safety, trip).

Table 6.

In addition, another analysis was performed based on the parameter concept level. As mentioned previously, primary concepts have closer relative spatial position in the concept map to the core concept of TE. This analysis by concept level, verified that concepts such as "traffic", "road transportation" and "infrastructure construction" are of ~~a~~ great significance among students' preconceptions as the most frequently used primary concepts. Considering that students point out these concepts first might imply that students assign them ~~a~~ greater significance during the process of concept map development. What was more important regarding these concepts is that in ECM, they converged in concepts such as "traffic signal design", "highway design", "pavement design", "road design", "traffic management", traffic control", "traffic flow" and "traffic forecasting". Some of these converged concepts confirm that students greatly increased their understanding about TE. In addition, another interesting observation was the increase in consistency among the primary concepts from BCM to ECM. However, a highest variance was found among the tertiary terms. Students often used tertiary concepts to provide examples for primary or secondary concepts, so one might conclude that beside similarity with the most important concepts there are potentially different students' perspectives about those concepts.

Finally, Table 7 below presents the least frequent concepts found in BCM and ECM. The column with BCM concepts shows that students have used mostly general concepts from a perspective of general engineering or as transportation users. On the opposite, concepts presented in the ECM column are more closely related to specific aspects of TE included in the course curriculum.

Table 7.

In-depth Analysis of Individual Student's Preconceptions

In order to perform a detailed analysis of student's preconceptions, the research team has used NVivo to run query analysis. Using queries, one can distinguish between concepts that have specific levels of relatedness or connectedness, and thus can identify positive or negative preconceptions.

Positive preconceptions

As positive preconceptions, the research team classified all those concepts coded to have high values of relatedness and connectedness. As a part of positive preconceptions, students frequently related construction, infrastructure management, geography or topography to TE activities. In addition, students recognized the importance of transportation for society (e.g., economy, jobs, budget), and safety as a very important goal of transportation systems. Besides this, students frequently recognized there are different transportation modes, and established a relation between TE and mass transit. As a part of less frequent but positive preconceptions, was the relation they acknowledge between physics and TE, considering the importance of vehicle dynamics in different transportation modes. Finally, mostly ISE students recognized the importance of traffic control, effects of congestion, focus of transportation on the movement of people or goods, and some specific tasks, such as finding optimal routes.

Negative preconceptions

Besides positive, potentially more important preconceptions are wrong or incomplete concepts. As negative preconceptions, the research team classified concepts that were matched to have relatedness of one (no relation) or two (very little relation). Firstly, one important misconception that students frequently used, was the relation of traffic and efficiency to negative connotations (e.g., traffic means bad flow, traffic causes pollution, traffic causes accidents, traffic means wasted resources, delay, wasted time). In addition, another important misconception was misunderstanding of traffic as a phenomenon (e.g., traffic flow as the amount of vehicles on the road, traffic control as the flow of traffic).

It is important to note that students, although recognized some individual concepts related to TE as significant and presented the connection between some TE aspects, they lacked the connection between other TE aspects. In addition, students established wrong or overgeneralized relations among elements (e.g., TE is affected by new technology), mentioned non-relevant concepts (e.g., optical instrument), and used non-engineering terminology (e.g., timeliness, implemented carefully). Moreover, CEE and ISE students related TE activities with enforcement, regulation, laws, or dealing with clients. As for younger students, an interesting observation was their ambiguity in understanding the relations between planning, design, operations, construction, and maintenance.

Overview of Evolving Concepts

Besides the frequency of concepts observed in BCM and ECM, the research team also decided to observe the relative percentages of concepts that are mentioned only once or twice. In BCM, 45.21% of concepts were mentioned only once or twice, while in ECM, this number was 29.12%. Furthermore, considering there is a smaller number of frequently used concepts in BCM, and greater percentage of concepts that are mentioned only once or twice, this shows that students' preconceptions at the start of the course had a high variance. On the contrary, at the end of the course, there was a significant increase in frequently used concepts.

Students' concepts in ECM were in general more specific to TE, but one important negative effect has to be noted here. In BCM, students frequently mentioned airports, trains, boats, or other concepts related to non-road transportation modes. However, the number of concepts related to non-road transportation modes have been reduced by more than a half in ECM. Figure 6 below shows an overall change in the relatedness and connectedness of concepts in BCM and ECM. One can observe that significant number of the concepts in BCM are assessed as having relative very good or lower relatedness and connectedness. On the other hand, concepts in ECM were mostly assessed as having excellent relatedness. The highest number of concepts in ECM is with only fair connectedness, which can be attributed to the content of the course. The potential drawback is that introductory TE course develops knowledge of specific TE concepts, but does not completely establish strong relations among them.

Figure 6.

LESSONS LEARNED AND RECOMMENDATIONS

The methodology proposed in this case study was designed to enhance the current teaching style rather than to replace it. First, this case study shows how to assess students' conceptual understanding, through course analysis, survey, and concept maps. Second, this case study shows that if students' preconceptions are taken into account when developing the learning environment, students can improve their conceptual understanding and metacognition. Considering the analysis presented in the previous section, the following are the major points related to students' preconceptions:

- Students had entering preconceptions relating TE to all transportation modes, infrastructure design and construction, traffic, safety, mass transit, and economy. Most of the primary concepts among students were similar, but tertiary concepts were different, thus potentially pointing out at differences in individual perspectives.
- CEE students had strong preconceptions that relate TE to infrastructure construction and safety.

- The preconceptions CEE/CEM students had in relation to construction, at the end of the course had evolved in relation to road and pavement design.
- ME students had a strong preconception about air and rail transportation as related to TE. In addition, similar to CEE students, ME students related safety to TE.
- ISE students had strong preconceptions about traffic flow, data and data analysis, logistics, queuing theory, and efficiency as related to TE.
- At the end of the semester, ISE students maintained some of their preconceptions related to flow and queuing theory, although their conceptions have evolved positively as well.
- Senior students had more preconceptions related to specific engineering activities (e.g., design), while sophomore and junior students had more preconceptions related to transportation as users.
- At the end of the semester, senior students have evolved their engineering perspective on TE, relating their understanding to concepts of infrastructure or systems. However, although junior students have modified their concepts (e.g., considering the importance of design), they have still maintained some of their previous perspectives on TE as transportation users.
- Students conceptions about TE have been expanded and were more similar at the end of the course, although there have been concepts that have evolved based on students major or year. Furthermore, students' preconceptions that related all transportation modes to TE activities have been modified with a focus only on road transportation.
- Student conceptions about TE were more general at the beginning of the semester and more specific at the end of the course. Thus many concepts students used in BCM, converged in ECM, pointing out to structuring of students' conceptual understanding.
- The "part-whole" relations between the concepts in ECM show how students construct their own knowledge and understanding of TE thus respecting their unique prior knowledge from different engineering fields and experiences as transportation users. The meronymy is stronger in ECM rather

than in BCM, since students construct relations in new contexts, showing deeper understanding about TE and TE activities, rather than just a general knowledge of what TE is.

- Students had positive preconceptions related to the importance of transportation for society (e.g. economy, jobs), safety, or importance of transportation on movement of people and goods. In addition, most students recognized different transportation modes, importance of finding optimal routes, and the effects of congestion in everyday life. First, these examples of positive preconceptions helped students to observe the transportation as a very important element of society. Second, these preconceptions helped students to create meaningful "part-whole relations" between TE related concepts, thus showing that students can successfully construct new engineering knowledge.
- Students had negative preconceptions related to efficiency of transportation systems, misunderstood traffic as a psycho-physical phenomenon, or related TE to marginal concepts, such as police enforcement, laws, or dealing with clients. As a result of these preconceptions, at the end of the course, some students still had some misunderstanding regarding transport externalities (e.g., traffic means bad flow, traffic causes pollution, and traffic causes accidents). In addition, some of the important missing preconceptions noticed, relate to driver psychology, human as a factor, and Intelligent Transportation Systems (ITS) technologies. These preconceptions prevented some students to establish a deeper relation between TE and ITS, or to understand the importance of drivers' psychology in traffic studies.

In conclusion, concept maps can serve to get more precise and consistent evaluation of students' conceptual understanding of the desired learning outcomes for TE education, and development of new social and cognitive skills. Resulting understanding about these preconceptions can be used in several different ways, to create different course improvements. For example, some of the information can be used to develop group discussion-based activities that involve students with different preconceptions, in order to create a beneficial knowledge overlap. Furthermore, identifying critical preconceptions that need to be expanded (e.g., strong relation between TE and construction) can lead to development of additional learning units based on other scientific disciplines. For example, these learning units can include emphasis on statistics, optimization, control theory, or sociology. Finally, another potential use refers to the implementation of concept maps as a method for student learning.

CONCLUSION

The need for this case study has been motivated by the consideration that people construct new knowledge based on the previous understandings and beliefs about important concepts. Consequently, ignoring students' preconceptions could result in negative effects on learning outcomes. Therefore, this case study argues the importance of students' preconceptions and their potential effect during the learning process. As a part of this case study, a methodology was devised for assessment of students' conceptual understanding, including course analysis, survey, and beginning and end-of-semester concept maps, as tools for preconception assessment. In addition, the methodology includes steps for creating, coding, and analytical assessment of concept maps. The presented research methodology is transferable, and provides a good starting point for other researchers that recognize the need to examine students' preconceptions. In other words, while this case study is a study with limitations, it is a favorable initiative to introduce the currently unexplored perspective of preconceptions in the process of knowledge creation among TE students.

Limitations and Implications for Further Research

- One limitation of this study is the number of participants. Therefore, further research should try to involve greater number of students for investigating their preconceptions.
- Another limitation is the possibility to compare the results with another case study done for the same course, CEE 3604, using only ECM. Future research, should consider the opportunity to observe a control group, where preconceptions are not taken into account at the beginning of the semester.
- Further research should investigate how positive and negative preconceptions affect students' learning process and what are the additional improvements to teaching or curriculum. In these future studies, special attention should be dedicated to tertiary concepts, considering their potential to point out at

differences in individual perspectives. Therefore, students should be encouraged to develop concept maps including tertiary concepts, in order to assess a complete depth of their understanding.

- Further research should also investigate how preconceptions based on student's major and year at the beginning of the semester affects student's knowledge at the end of semester. This analysis can be used to propose further enhancement in teaching methods and curriculum development.
- Considering the diversity in majors, it would be beneficial to investigate further preconceptions of students majoring in CE; bearing in mind that they constitute the majority of future transportation workforce. This need is supported by the fact that the majority of preconceptions related to transportation systems originate from ISE students, while CEE students have mainly preconceptions related to transportation infrastructure.
- One of the conclusions of this research is that students' preconceptions about TE, as including several transportation modes, were modified during the course with a significant focus on road transportation. As previous research mentions (Sinha et al., 2002), this point might lead to the old debate of breadth vs. depth in transportation education. The question of the focus of TE education becomes even more complex taking into consideration the development of Intelligent Transportation Systems technology and consequent evolving paradigms in TE profession. On the contrary, initial course analysis pointed out that CEE 3604, as an introductory TE course, faces high expectations originating from a range of course objectives, ABET criteria, and essential learning goals. Considering this evolving focus of the TE profession, future research should include expert opinions on important introductory concepts in transportation engineering, and the way course curriculums are structured (Rod E Turochy, 2006; Rod E. Turochy et al., 2013). Finally, considering the high expectations from introductory TE course, a larger research question should focus on investigating a number and content of required TE courses for CE students.

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DISCLAIMER

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TABLES

Table 1. Teaching goals inventory

Cluster	Goals Included in Cluster	Percent Rated "Essential"	Average Rating
Higher-Order Thinking Skills	1-8	25%	3.88
Basic Academic Success Skills	9-17	0%	1.56
Discipline-Specific Knowledge and Skills	18-25	63%	4.5
Liberal Arts and Academic Values	26-35	0%	2.4
Work and Career Preparation	36-43	0%	2.25
Personal Development	44-52	11%	2.11

Table 2. Pre-course survey questions and answers

Question	Answers		
Why did you select this course?	– Interested in roads and transportation. Might want to pursue a career in transportation. – I have always been interested in transportation particularly in public transit. I take public transit often sometimes across multiple states and while the US public transit is manageable, it could certainly be improved a great deal so I want to learn more about it. – To learn more about the study of transportation and understand concepts behind traffic flow. – I thought it would pertain to Industrial and System. – I wanted to learn more about how roadways are designed and traffic flow is managed.		
What are your learning expectations from this course?	– Learn about transportation as a science. – Learn why traffic is horrendous in Northern Virginia! Also, want to know how traffic can be managed logistically. – I want to explore traffic control methods. – More in-depth knowledge regarding the engineering concepts behind transportation engineering. – I expect to learn a little about a lot of different areas of transportation including cars, roads, systems, infrastructure and hopefully public transit as well. – To be able to handle large transportation problems.		
Name your previous courses that you think will help you learn during this course?	answers from CEE and CEM students	answers from ME students	answers from ISE students
	- Environmental Engineering - Building Materials - Introduction to Civil Engineering	- System Dynamics - Fluid Dynamics - Vehicle Dynamics - Physics	- Simulation - Probabilistic Operations Research - Statistics and Mathematics - Production and Operation Management - Deterministic Operations Research - Operations & Supply Chain Management

Table 3. Concept map assessment rubric

	Excellent	Very good	Fair	Very little	No credit
RELATEDNESS	The concept denotes a clear terminology and strong understanding of the core concept. The concept can be evidently related with concepts shown in Figure 4 and vice versa.	The concept denotes a clear terminology and some understanding of the core concept. The concept can be related with concepts shown in Figure 4 and vice versa.	The concept denotes a clear terminology and some misunderstanding of the core concept. The concept can be fairly related with concepts shown in Figure 4 and vice versa.	The concept denotes fairly clear terminology and misunderstanding of the core concept. The concept can be somehow related with concepts shown in Figure 4 and vice versa.	The concept denotes unclear terminology and no understanding of the core concept. The concept cannot be related with concepts shown in Figure 4 and vice versa.
CONECTEDNESS	The concept is interlinked with many other concepts. The concept represents significant hyponymy relations with the neighboring concepts. There is a superior level of clarity in the logical sequence of part-whole relations between the observed concept and the neighboring concepts.	The concept is interlinked with several other concepts. The concept represents hyponymy relations with the neighboring concepts. There is a high level of clarity in the logical sequence of part-whole relations between the observed concept and the neighboring concepts.	The concept is fairly interlinked with other concepts. The concept represents some hyponymy relations with the neighboring concepts. There is some level of clarity in the logical sequence of part-whole relations between the observed concept and the neighboring concepts.	The concept is interlinked with one or two other concepts. The concept represents few hyponymy relations with the neighboring concepts. There is a poor level of clarity in the logical sequence of part-whole relations between the observed concept and the neighboring concepts.	The concept is interlinked with no other concepts. The concept represents no hyponymy relations with the neighboring concepts. There is unclear level of clarity in the logical sequence of part-whole relations between the observed concept and the neighboring concepts.

	Primary	Secondary	Tertiary
LEVEL	The concept is located in the immediate vicinity of the core concept. There is a direct connection to the core concept or there is only one primary concept in between.	The concept is located further away from the core concept. There is at least one primary concept between this concept and the core concept.	The concept is located at the edge of the concept map. There are several primary and secondary concepts between this concept and the core concept.

Table 4. Word frequency analysis for all of the BCM and ECM and the relative difference

BCM		Difference	ECM	
Word	freq.		Word	freq.
roads	34	10	**traffic**	57
traffic	31	-26	**design**	54
design	21	-33	pavement	24
construction	16	12	roads	24
cars	13	11	**highway**	19
flow	11	-6	**flow**	17
minimize	11	11	signal	16
highway	10	-9	rigid	16
safety	9	-1	flexible	16
transportation	9	1	lane	13
engineering	8	3	horizontal	12
time	8	2	type	12
air	7	6	**vehicles**	12
efficiency	7	3	vertical	12
infrastructure	6	0	queuing	11
limited	6	3	performance	10
logistics	6	5	**safety**	10
system	6	4	speed	10
people	6	2	curve	9
public	5	1	transportation	8
management	5	4	multilane	8
airports	5	4	trip	8
civil	5	2	signals	8
control	5	0	forecasting	7
vehicles	5	-7	service	7

Table 5. Most frequently used concepts for BCM and ECM per student's major

BCM - CEE/CEM		BCM - ME		BCM - ISE	
Word	freq.	Word	freq.	Word	freq.
construction	8	traffic	7	traffic	17
design	7	air	3	design	11
traffic	7	design	3	flow	8
road	6	engineers	3	minimize	8
highway	4	people	3	time	6
safety	4	public	3	data	5
infrastructure	3	safety	3	logistics	5
ECM - CEE/CEM		ECM - ME		ECM - ISE	
traffic	20	**design**	10	**design**	30
design	12	**highway**	7	**traffic**	28
curve	6	**traffic**	6	vehicles	17
population	5	element	5	**highway**	16
highway	4	alignment	4	**pavement**	16
road	4	flexible	4	**road**	16
pavement	4	**flow**	4	**flow**	10

Table 6. Most frequently used concepts for BCM and ECM per student's year

BCM – senior		BCM - junior/sophomore		ECM - senior		ECM - junior	
Word	freq.	Word	freq.	Word	Count	Word	freq.
roads	25	roads	9	design	39	traffic	22
traffic	23	traffic	8	traffic	35	design	15
design	17	construction	7	highways	23	vehicle	7
minimize	11	**management**	3	**pavement**	20	vertical	6
construction	8	**population**	3	roads	18	curve	5
engineering	8	**build**	2	**flexible**	14	highway	5
flow	8	**building**	2	**rigid**	14	horizontal	5
maximize	6	**geographical**	2	**signal**	12	performance	5
safety	7	**goods**	2	**queuing**	9	**population**	5
air	7	**growth**	2	**speed**	8	**trip**	5
limited	6	**move**	2	**horizontal**	7	**safety**	5
efficiency	5	**people**	2	**signals**	7	pavement	4
planning	5	bridges	2	**vertical**	6	signal	4

Table 7. Least frequently used concepts for BCM and ECM

BCM	ECM
acceleration, **access**, **aircrafts**, **airplanes**, **airport**, alignment, analysis, **architecture**, area, **CAD**, capacity, center, **city**, commercialization, **computer**, concrete, conditions, **conveyors**, **culture**, demand, destinations, devices, **disaster**, draft, dynamics, **economics**, emissions, environment, errors, **ethics**, foundations, **freight**, funding, **geology**, grade, guidance, guidelines, **hill**, hypothesis, idea, **improvements**, **jobs**, **labor**, lakes, land, lanes, limit, limitations, logic, **mall**, **mass**, material, **method**, **metro**, mode, **money**, **mountains**, number, objective, observation, obstacles, **online**, optical, optimal, order, organized, outcomes, **overloaded**, parallel, **passenger**, path, **pedestrians**, persons, **prevention**, probability, problem, processes, **profit**, purpose, quantity, **railtrack**, ramps, regulations, ridership, route, **runways**, satisfaction, ship, signal, signs, **simulation**, sinage, **software**, **stakeholders**, stoplights, strategy, structures, sustainability, **terminals**, timeliness, topography, traveling, **trucks**, **users**, variables, way, weight (1)	**accessibility**, **accidents**, **aerodynamic**, air, airplane, alignment, areas, **arrivals**, attitude, automobile, aviation, background, **barrier**, base, behavior, breaking, **budget**, building, cargo, chart, cities, congestion, **coordination**, **crashes**, **crest**, daily, data, **deceleration**, delay, **departures**, **diagrams**, direct, **distribution**, **distributions**, division, **drag**, driver, economy, efficiency, emissions, enforcement, engineer, **eyesight**, factor, failure, fares, **FIFO**, foot, **forecast**, formula, free, freight, **frequency**, **fuel**, fundamentals, **geometrical**, goods, grades, **gravitational**, **green**, guide, guidelines, industrial, information, infrastructures, **jam**, jet, jobs, land, life, **lifespan**, **LIFO**, **light**, **lights**, limit, lines, local, logistics, **macro**, **macroscopic**, management, **markings**, material, materials, measurements, method, **micro**, **microscopic**, **model**, motive, multi, numbers, observation, **optimal**, **optimization**, **optimized**, overloaded, **parameter**, passenger, **pavements**, pedestrians, perception, planes, police, pollution, ports, **power**, prediction, preparation, **priority**, problem, procedures, products, project, **psychology**, rail, rails, railways, ramps, **random**, **rate**, recreation, regional, regulations, **reliability**, research, **resistances**, resources, ridership, **ring**, runways, safe, **sag**, **schedules**, scientist, section, semi, **serviceability**, services, ships, **sight**, situation, **slab**, snow, **spacing**, specification, **SSD**, standard, standards, **structure**, study, subway, **surface**, survey, surveys, sustainability, systems, tandem, taxes, taxi, technology, trains, traveling, trolley, understandable, values, variables, variety, wasted, water, width, **yearly**, **yellow** (1)