



Transportation Engineering Education in the 21st Century: A Review of Current Practices

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Abstract

The transportation systems currently in place in the United States affect every citizen on a daily basis. For these major critical infrastructure systems we expect the individuals responsible for creating, building, and maintaining these systems to be well qualified to do so. The question must then be asked; for tasks and responsibilities so immense, will there be enough qualified transportation engineers to continue to maintain the current infrastructure and be prepared to handle the challenges of tomorrow? This paper explores the current state of the transportation engineering workforce and the current practices within transportation engineering education in civil engineering undergraduate programs.

An analysis of the current trends in population and urbanization shows an increased need for infrastructure expansion and renewal. This in turn will increase the demand for competent transportation engineers. In order to meet this prospected demand, undergraduate programs need to not only inspire more students to pursue transportation engineering, but also ensure they gain the required body of knowledge to assess and address the transportation problems of the future. A review of various engineering education journal articles and conference papers sheds light on the current efforts to increase undergraduate interest in transportation engineering and better prepare them for the workforce.

Transportation engineering education varies based on the approach which civil engineering undergraduate programs use to educate their students. Various structures of introductory, intermediate, and capstone courses exist at most educational institutions. However, they tend to cover the same essential concepts and materials. The findings of this paper will aid in future transportation engineering curriculum changes aimed to better prepare students for the workforce and potentially increase student retention rates.

Introduction

As the population in the United States grows, there will be an increase in demand for travel and improved transportation services and facilities [19] & [21]. Transportation engineers are responsible for helping society meet their needs through providing transportation infrastructure and improving that which is already in place. In 2016, 303,500 civil engineers were employed in the United States and that number is slated to increase by 10.6% by 2026 [24]. This increase in demand will create unprecedented challenges in recruiting and retaining the workforce for transportation agencies at the federal, state, and local level in addition to the private sector [21]. These challenges are caused by a myriad of changes to the field, as described by the Transportation Research Board in 2003. These changes include new transportation methods, materials, and technologies, program growth to meet the rising needs of everyday travelers and shippers, expanding technical and environmental issues, and the large number of retiring baby boomers leaving the workforce. Similar problems were faced in 1985 when many within the profession were retiring [21]. More than 30 years later it was predicted that fifty percent of the transportation workforce would be eligible for retirement in 2016 [22]. As such there is an

increased need for transportation engineers that are well equipped to handle not only the challenges of today but those of tomorrow as well.

This literature review explores the current practices within transportation engineering education in civil engineering undergraduate programs in order to assess their ability to create the required transportation engineers. To accomplish this, this paper includes the history of transportation engineering education, transportation course requirements for graduation, the current state of the typical introductory transportation engineering course and capstone design course, and the relevant contents of the latest civil engineering body of knowledge report.

Background

The knowledge and skill set required to be a successful transportation engineer is constantly evolving. Throughout history, the education of professionals within the field in the United States has been closely related to the development and growth of the nation's transportation systems [12]. When railroads were the predominant form of transportation, the education of engineers was mainly dedicated to railroad engineering, but once automobiles were privatized the education emphasized highway design and building to create a national system of interstate and defense highways [12]. During this time state highway departments began to team up with local universities [19] to fulfill the rapidly growing need of roadway systems. In the late 20th century another shift occurred to support the development of public transportation systems in cities.

Since then construction of new systems has diminished and educational priorities have become system operations, safety, and Intelligent Transportation Systems (ITS) applications [12] & [22]. The transportation engineering discipline will continue to take advantage of the information revolution, developing vehicles and infrastructure elements that are able to sense the environment around them and communicate to operating agencies [19]. In the coming years, as technology evolves, transportation engineers and the education they receive will require the ability to adapt and create solutions to challenges as they arise.

Transportation Engineering Course Requirements for Graduation

In most undergraduate programs, civil engineering students do not encounter transportation engineering until their third year [13]. The requirement of various transportation courses varies from program to program; however, over three quarters of civil engineering programs require at least one course specifically focusing on transportation [22]. Due to their nature, transportation engineering courses cover concepts that are not touched upon in students' previous course work [13]. This aligns with the need for at least one transportation course to be required for graduation. The most pressing debate within transportation engineering education today is of breadth versus depth in the introductory transportation engineering course as universities continue to struggle with which topics and additional issues (such as policy, energy, environment, and technology) to include [19]. The following section furthers the discussion on this introductory course and its contents.

Introductory Transportation Engineering Courses

An introductory course is often the first exposure to transportation engineering that civil engineering students receive in their undergraduate career. This course has the ability to inspire students to pursue more advanced transportation engineering courses and ultimately a career within the field. In order to gain students' attention, introductory courses require effective strategies [23] of presenting relevant content including active learning techniques.

Content Needs

When determining the content of an introductory transportation engineering course, there are many considerations. The purpose of this type of course is merely to introduce students to the most prevalent topics within transportation engineering and as such does not provide a complete understanding of the field. Thus its relationship to follow-up or more advanced courses [22] must be taken into account. The later, more advanced courses have the opportunity to give more in depth information on topics covered and even introduce new topics that were not included in the introductory course. The setting and demographics of university districts can also affect the content of the course. Undergraduate students can receive jobs in and around the same location of their alma mater, which leads to the need to gain knowledge of the geography and population to be a successful transportation engineer in that area. Turochy [22] gave the example of “an institution located in a large metropolitan area may place a higher value on a multimodal approach (including coverage of mass transit systems) than an institution in a small college town” (p. 202).

The increase of information technology applications, including simulations, in recent years has created the need to educate future engineers on the use of them and how to interpret their outputs. This adds another topic to the already expansive course syllabus. The fact that transportation agencies are becoming increasingly more multimodal while private sector consultants are receiving more work [22] must also be taken into consideration when choosing the content of an introductory course. This course has the responsibility of giving students an overview of what a transportation engineer does and as such must introduce them to the work environments available to them if they choose to pursue a career in the field. Finally, for those students not interested in becoming a transportation engineer, an introductory course must at least prepare them for the transportation portion of the civil engineering Fundamentals of Engineering (FE) examination [22]. An introductory course can easily cover the topics within the current transportation engineering component of the FE Exam. Those topics include geometric design of streets and highways, geometric design of intersections, pavement system design, traffic safety, traffic capacity, traffic flow theory, traffic control devices, and transportation planning [16].

In 2006, Turochy completed a study to determine the needs of the transportation engineering profession through surveying transportation engineers and comparing his results to the results of a similar survey conducted in 1985 by Khisty [14]. In both surveys, the transportation engineers were asked to score topics on a 1 to 5 scale, with 1 being a topic of the lowest priority and 5 being a topic of the highest priority, and then ranked each topic based on their relative importance [22]. Between the two studies there was little change in relative importance of many

topics like geometric design of highways, highway capacity studies, and transportation planning. However, there were some topics that significantly grew or declined in importance [22]. Topics related to traffic management, mobility, safety and ITS applications grew in their importance between 1985 and 2006 while topics with contract-related issues declined in importance. These findings could be related to the increasing traffic congestion between the two surveys and the idea that contracts can be covered in a required construction course or later transportation courses [22]. The main learning objectives of a typical introductory transportation engineering course will most likely stay consistent. However, the extent to which certain topics are covered will depend on the trends within the profession at the time.

National Transportation Curriculum Project

In June 2009 a Transportation Engineering Educators Conference was held to allow collaboration between university faculty and transportation practitioners on the average introductory transportation engineering course [23]. Presentations on innovations within transportation engineering education and workshops on how to create active learning environments and how to define the learning domain for the introductory course were available to over 60 participants

[23]. The outcomes of the conference as described by Bertini & Kyte [3] are as follows:

- It is critical that the one or two required undergraduate transportation engineering course(s) address a minimum set of core competencies (“learning domain”).
- There should be a common set of knowledge tables that map the learning domains which could be used by instructors across universities as the basis of the required course(s).
- There is a need for effective strategies that provide contextual active learning environments for students in these courses.
- There is a need to develop collaborative tools for sharing transportation engineering curricular materials across instructors and institutions.

In response to these outcomes, around 20 transportation engineering educators created the Curriculum Subcommittee of the Institute of Transportation Engineering (ITE) Education Council. This subcommittee’s goal was to build upon the work done at the conference in the form of a review of efforts to develop bodies of knowledge and learning outcomes that included various methodologies and approaches [23] that culminated in the creation of the National Transportation Curriculum Project (NTCP) [17]. Due to the concern that the average transportation engineering course does not meet the needs of students and the profession, the NTCP focused on the typical introductory transportation engineering course at the undergraduate level [17]. The NTCP created learning outcomes, knowledge tables (including concepts, processes, tools, and contexts), and desired ways of being for transportation engineers and their lifelong skills (each defined as cognitive, social, or affective) for an introductory transportation engineering course [23]. In addition, the NTCP has educated faculty on the importance of active learning techniques and facilitated the development of learning and assessment activities for transportation engineering courses. A repository of content created has been made available online in the hopes of encouraging awareness and adoption [17]. The

Curriculum Subcommittee then decided to assess the usefulness of their creations through designing and revising an introductory course. The learning outcomes and knowledge tables were piloted at three institutions [17]. One such pilot is described in the following section.

The 2012 Transportation Engineering Educators Conference/Workshop focused on educators and their level of comfort with active learning as a pedagogical approach and promoting further development, sharing and adoption of materials through the formation of collegial networks [17]. While all conference participants cared about workforce development and the future of the profession, they lacked collaborative networks between institutions that would allow for significant change. Borrego et al. [5] suggests that networks are paramount in promoting the adoption of educational change by faculty members. As a result the conference allowed participants to share best practices and learn new approaches to improve student learning in an introductory transportation engineering course. Throughout the conference, the focus on implementation of active learning and conceptual assessments within an introductory course were supported by the creation of a large network of transportation faculty members from various institutions [17]. The creation of the NTCP and the work done at both the 2009 and 2012 conferences show the motivation within transportation engineering educators to address the challenges of educating, recruiting, and retaining students in the profession.

One Approach to Increase Depth

Young et al. [23] piloted the NTCP learning outcomes and knowledge tables in their revision of an introductory transportation engineering course. As an introductory course, it may be the only occasion students are exposed to the transportation profession during their undergraduate career and in turn the only opportunity to gain their attention. With this in mind, Young et al. [23] asked the question, “What is the impact on students of designing/revising a course based on these learning outcomes and knowledge tables?” The original course emphasized exposure to many different topics within transportation engineering rather than depth in a few topics. The course instructor redeveloped the course to include further depth into the most critical topics and reduce breadth using the knowledge tables and course outcomes created by the NTCP.

Keeping in mind the school’s geographic region and the interest of the students, the total number of topics in the course was reduced by about 25% [23]. To provide more depth to the remaining topics, process level activities and extended lab sessions for software and topic integration were introduced. Due to the changes made, student comprehension of material increased while memorization became less important [23]. A pre and post survey of the students’ perceptions of the transportation engineering field indicated improvements to the level of interest in transportation as a potential profession. Overall, the NTCP knowledge tables and course outcomes helped the instructor to implement changes to the introductory transportation engineering course that positively affected student learning and perceptions.

Senior Level Transportation Design Courses/Capstone

ABET has created criteria for various undergraduate engineering programs including civil engineering. As of 2016, civil engineering programs must create opportunities for students to “design a system, component, or process in more than one civil engineering context” in order to be accredited [1]. This requirement of a design experience has led to the necessity of a senior

level design course or capstone within civil engineering programs. Since there are a wide range of focuses available within civil engineering, many programs offer transportation engineering design project options as part of the larger civil engineering capstone course. In this section, the need for design courses is discussed further along with a discussion on the positive outcomes of an engineering design course and two examples of capstone design courses, separated by 20 years.

Need for Design Courses

Like any other engineer, transportation engineers must be capable of engineering design. Dym, Agogino, Eris, Frey, & Leifer [9] define engineering design as:

“A systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints.”

A graduate entering the transportation engineering profession is expected to have experience in performing engineering design and working on teams. Capstone courses are referred to as providing this design and team experience for undergraduate students [9] and provide them with the skills associated with a good designer, described below:

- Tolerate ambiguity that shows up in viewing design as inquiry or as an iterative loop of divergent-convergent thinking
- Maintain sight of the big picture by including systems thinking and systems design
Handle uncertainty
- Make decisions
- Think as part of a team in a social process
- Think and communicate in the several languages of design

All of these skills are those of a competent transportation engineer and are often difficult to fully learn and master during the undergraduate education without enrolling in a capstone course. The engineering problems set forth in a capstone course have multiple alternative known and unknown possible solutions. The student must disclose the alternative known solutions and generate the unknown possible ones by using divergent thinking, a process by which one tries to diverge from facts to the possibilities that can be created from them [9]. As divergent thinking is not recognized clearly or performed well in most engineering curricula [9], it is of the utmost importance that students are provided with the opportunity to enroll in a capstone design course where it is.

Throughout the years, engineering curricula have gone through a transition from a focus in practical experiences to scientific and engineering theory as reported by Seely [18]. For the last five decades engineering has been taught only after solid foundational knowledge in science and mathematics has been acquired [9]. Those teaching engineering, namely design, have felt that leaders of engineering departments are unable or unwilling to recognize the resources demanded to support good design courses [20] and as such are not provided the necessary resources for such an endeavor. However, the average capstone design course has evolved from

'made up' projects created by faculty to industry sponsored projects with real-world problems. Expertise and financial support are now provided by companies to enhance the projects further [8], [6], [9]. Faculty investment of time and money into capstone courses provides students with valuable learning experiences that they will be able to draw upon while in the workforce.

Initial changes in engineering education to include capstone design courses were brought about by employers who indicated a need for engineers that are adept communicators, good team members, and lifelong learners in addition to being experts in their field [9]. Similar to the notions of De Graff & Ravenstijn [7], Dym, Agogino, Eris, Frey, & Leifer [9] call for an engineer that must understand the constraints of design with a global, cultural, and business context and therefore demanding that educators look beyond the limits of their own institutions when creating design courses. The transportation engineer of tomorrow must not only be an expert in the field and capable of innovative design, but also be able to communicate and empathize with people they are creating for. In order to achieve this type of engineer it is important for transportation educators to emphasize the need for students to cultivate the necessary social skills along with technical expertise. Educators are also encouraged to be aware of the current engineering education research related to this 'well rounded' engineer so that it may inform their practice.

Basic Capstone Design Course

Due to the increased emphasis on design courses by ABET, capstone design courses have been required at various institutions since the early 1990s. At the time, North Dakota State University held a civil engineering capstone design course that included projects with topics that covered many aspects of civil engineering including transportation [2]. The course was meant to be an accumulation of previous curricular components in addition to an engineering design experience. Each civil engineering faculty member acted as a mentor and a resource in their particular area of expertise which included conducting a weekly lecture period covering technical topics [2]. Much like in the real world, student groups gave oral reports on their progress and were asked to produce written documentation. As reported by Andersen [2], "an important benefit of the project was an appreciation for working together as a group to accomplish an overall goal." These aspects of the course helped students to develop the soft skills (communication and social skills [7]) needed to be a successful engineer. Like the students of today, Andersen's [2] students were frustrated by the lack of input information given, however, this experience provided a valuable glimpse into the reality of being a civil engineer.

Project-based Learning in Action

Universities are facing industry requirements for a wider skill base in graduates while the increasing availability of information is changing the way students learn. Both are causing a state of flux within engineering education [11]. Problem-based learning allows students to take control of what needs to be learned and how it should be learned while providing an opportunity to develop teamwork, problem solving and leadership skills [7]. While there is definite support for problem based learning in the literature, few illustrate how it can be implemented within civil engineering education. In the hopes of filling the void, Gavin [11] suggests that "problem based learning should be used as a partial solution to develop

professional problem-solving skills through the application rather than the acquisition of knowledge” and as such uses project-based learning in his capstone design course. Gavin’s [11] review of project-based learning was in context of a capstone design course that is focused on structures engineering; however, the pedagogies described can be easily transferred to transportation engineering design. In the course, learning is directed by the problem itself and students are required to guide themselves toward a solution. Self-reflection through questions such as ‘What did I learn?’ and ‘What further knowledge do I need?’ can help guide students throughout the design process [15]. This method needs less scaffolding and support as students are applying knowledge previously obtained and can be overseen by a floating facilitator [11].

The majority of the projects were created by experts from industry and are based on current projects [11] which gave students valuable experiences that are relevant to what they will face after graduation. However, students in their fourth year of higher education are unlikely to fully recognize the benefits of such an experience if left to do so on their own. To help students recognize the benefits, an introduction to the project-based learning process, guidance for how to work in groups, learning objectives, and weekly feedback from faculty and external experts were provided [11]. The support given by the faculty has the ability to gradually introduce students to real world design aspects and positively affect the outcomes of the course. Overall, project-based learning is an effective approach to teaching design and the necessary skills for success in the transportation engineering field.

Body of Knowledge & Faculty

While the skills required of a practicing transportation engineer are not necessarily coincident with a general civil engineer [19] the universal requirements of all civil engineers set forth by the American Society of Civil Engineers (ASCE) still apply to transportation engineers. ASCE has created a body of knowledge by which the profession’s members study and build careers [4]. In order for civil engineering students to obtain a specific body of knowledge, it is essential that their educators stay up to date with the changes to the field and the requirements of its professionals.

BOK2 is the second iteration of the ASCE’s civil engineering body of knowledge that is a prerequisite for entry into the practice at a professional level and for licensure [4]. This iteration was called for by stakeholders and recent developments in engineering education and practice. It expands the previous outcomes by adding specificity and clarity using Bloom’s Taxonomy. A student will fulfill the BOK2 through formal education, a bachelor’s degree plus a master’s degree, and experience [4]. While the complete BOK2 cannot be accomplished through a bachelor’s degree alone, majority of the achievements within the BOK2’s outcomes are to be fulfilled through the earning of a bachelor’s degree, as declared by the outcomes rubric. The ASCE created the BOK2 to provide a framework with which stakeholders can clearly understand the standard to which they hold civil engineering professionals. ABET leaders can use the BOK2 as a basis for creating accreditation criteria while prospective civil engineering students are provided with a general understanding for the opportunities within the field [4]. Researchers are offered ideas on future directions including within engineering education while civil engineering faculty can use the BOK2 to assist in the design of curricula and improvement of courses.

The BOK2 goes as far as defining characteristics of civil engineering faculty members that will best aid their students' learning. These characteristics include scholarship, effective teaching, relevant practical experience, and being a positive role model [4]. It is expected that faculty members maintain a high level of expertise and relevant experience in the courses they teach. Being an effective teacher requires a dedication to student learning and bettering one's teaching through pedagogical training [4]. However, in many cases civil engineering faculty have little to no pedagogical training and it is not required within the hiring process. This is one area where the greatest improvements can be made to transportation engineering education. Giving transportation engineering faculty training throughout their careers would give them the ability to better transfer knowledge to their students. Finally, faculty must be aware that students view them as a role model for the profession [4]. For all students, but even more specifically for minority engineering students, this is a component of whether or not they believe they are capable of being an engineer that they can fit into that role. The BOK2 is comprehensive in its ideal civil engineering faculty member but the question is, how many faculty members fit that description?

The BOK2 is not the only place in the literature where transportation engineering educators are held accountable. Hurwitz, Bernhardt, Turochy, & Young [13] performed a systematic literature review of the existing body of knowledge of transportation engineering educators in order to lead such educators to improved teaching and learning. Currently within transportation engineering education, courses often lack connections with previous undergraduate course work. This presents an opportunity for new learning but can also prove to be a difficult transition. Like many other engineering fields, most transportation engineering educators are working under dual objectives, teaching and conducting research [13]. Faculty members are struggling to remain innovative and fully aware of different pedagogies that would increase student learning because of the time constraints put on their schedule by research requirements. Through all of this some transportation educators have been able to publish scholarly work for over 18 years on instructional practices including problem-based learning and tools for simulation and visualization [13]. Hurwitz, Bernhardt, Turochy, & Young [13] suggest that educators looking to implement new teaching and learning techniques in the classroom should use scholarly publications, especially those included in their review, as a starting point. Furthermore, they put out a call for a stronger community of transportation engineering education practice in order to increase dissemination of ideas and adoption of best practices across institution boundaries.

Conclusion

It is clear that transportation engineers are in demand based on the growing population and its needs for travel. Industry is requiring graduates to come fully equipped with not only the technical skills needed to be an engineer but also the communication skills, social skills, and the ability to empathize with society as well. Throughout this review, methods of active learning have arisen as ways to better engage students in transportation engineering and the design process. It has become imperative that transportation engineering educators become aware of their students' learning needs and the expectations of industry. They must take the time and resources to better their own profession of teaching and learning so that students develop an interest in becoming transportation engineers and are ready and able for the challenges ahead. Educators need to invest in their students' ability to deal with complex problems through

synthesis of knowledge to prepare them for the lifelong learning necessary to remain relevant as a professional [10]. No one transportation engineering educator can make these changes alone, they must rely on a network of inter-institutional colleagues eager to make change. Moving forward, collaboration tools must be created in order to foster this strong network and to allow further dissemination of research findings. Transportation engineering educators should look to these research findings to inform changes made to their courses and teaching methods. In turn, educators should publish their results of changes they've made in the classroom. If we are to meet the growing transportation needs of society, we must first meet the needs of our students in their pursuit to cultivate the necessary body of knowledge for success in this field.

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