Transportation Engineering Instructional Practices

Analytic Review of the Literature

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Instructional practices in transportation engineering education are evolving, and only some of these changes have been documented in the literature. This paper provides a systematic review of journal articles and refereed conference papers that address innovations in transportation engineering education; the focus is on novel instructional practices and their influence on student learning. The literature review finds 46 articles for analysis, with an increasing frequency of those publications over time. Instructional practices described in these papers include simulation, visualization, problem-based learning, and other active-learning techniques. Most of these articles were written by individual researchers or a team of researchers at a single institution, and few of the articles cite one another; this finding suggests a need for more effective dissemination. Techniques for measuring student learning include in-person interviews, a variety of survey types (typically multiple choice or open-ended), concept maps, and direct assessment of student work. These techniques are implemented mostly as postassessments, but in some work, a pre- and postcourse experimental design is employed. It is clear that more rigorous evaluation of student learning, resulting from changes in teaching practices, should be considered. This analytical review of the literature provides a resource for transportation engineering educators to identify pedagogical practices that are relevant to their courses and suggestions for how to measure the effect of these techniques on student learning.

Transportation engineering can be a more challenging subject to teach than its civil engineering counterparts for several reasons, including the lack of upstream courses found in other subdisciplines (*1*). For example, within the structures area, students are shown simple structural systems and analysis techniques from their first year of college and then led through a series of classes with increasing complexity. In most programs, students do not encounter the transportation field until the junior year (*2*). In addition, unlike other civil engineering subdisciplines, much of the transportation field, outside of roadway design and pavements, is not mechanics based. Although some areas of traffic engineering benefit from analogies to hydraulics, other areas lack significant connection with students' previous course work. Further, a broad understanding of the transportation field requires knowledge in areas traditionally outside of engineering, such as public policy, economics, and human factors.

Transportation engineering education is similar to other civil engineering subdisciplines in that faculty members responsible for instruction spend much of their available research time on their technical subject areas instead of on engineering education. With most educators working under the dual objectives of teaching and conducting technical research, knowledge transfer of educational developments lags that of technical issues. A systematic review of transportation engineering education research will benefit all transportation engineering educators and will increase the rate of knowledge transfer and of implementation.

There is a significant and growing need to foster rigorous analytic literature reviews in engineering education (*3*). A search for transportation engineering education literature showed that a systematic review of the literature, with a focus on instructional practices, or on any other pertinent topic, has yet to be documented. Examples of seminal analytic reviews from engineering education include work by Johnson et al., who reviewed active and collaborative learning (*4*), and Henderson et al., who reviewed the facilitation of change in undergraduate instructional practices in science, technology, engineering, and mathematics (*5*). Such research efforts are critical in the documentation of research accomplishments and the identification of research needs (*3*).

This work serves as a resource for (*a*) transportation engineering educators, who will be able to better use the existing body of knowledge, thus leading to improved teaching and learning through more effective knowledge transfer about classroom practices and available tools, and (*b*) transportation engineering education researchers, who will have a better understanding of the gaps in the existing literature and can work to fill them. Both are important because pressures on transportation educators are expected to increase as the profession continues to broaden, the tools become more complex, and the needs of the transportation profession continue to increase.

This paper begins with a description of the methodology for the review. Next, it discusses the results in terms of the selected articles, efforts related to innovative teaching practices, and studies that discuss efforts to measure the efficacy of these practices. Finally, the paper assesses the state of the field and suggests next steps for researchers and educators. It is not the intent of this systematic literature review to make recommendations on teaching practices beyond what is reported in the cited literature.

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METHODOLOGY

A systematic literature review follows a specific sequence of steps to ensure that it captures the intended scope and addresses the research questions being asked. The approach in this paper, based on that suggested by Borrego et al. (*3*), employs four steps: (*a*) defining research questions, (*b*) defining a scope of inquiry, (*c*) finding sources, and (*d*) applying exclusion criteria (Figure 1).

Research Questions

Carefully articulated research questions and a clearly defined scope of inquiry are required to determine whether a study should be included for further analysis within the review. If the research questions are too broadly defined, it may be difficult to arrive at a concise article database. The two primary research questions are as follows:

1. What instructional practices have transportation engineering educators used to improve student learning at the undergraduate and graduate levels?
2. What techniques have been used to measure student learning in transportation engineering education?

Finding and Cataloging Sources

The scope of the sources for this analytical review was limited to refereed journal articles and refereed conference proceedings to increase the likelihood that the documents considered for inclusion would be

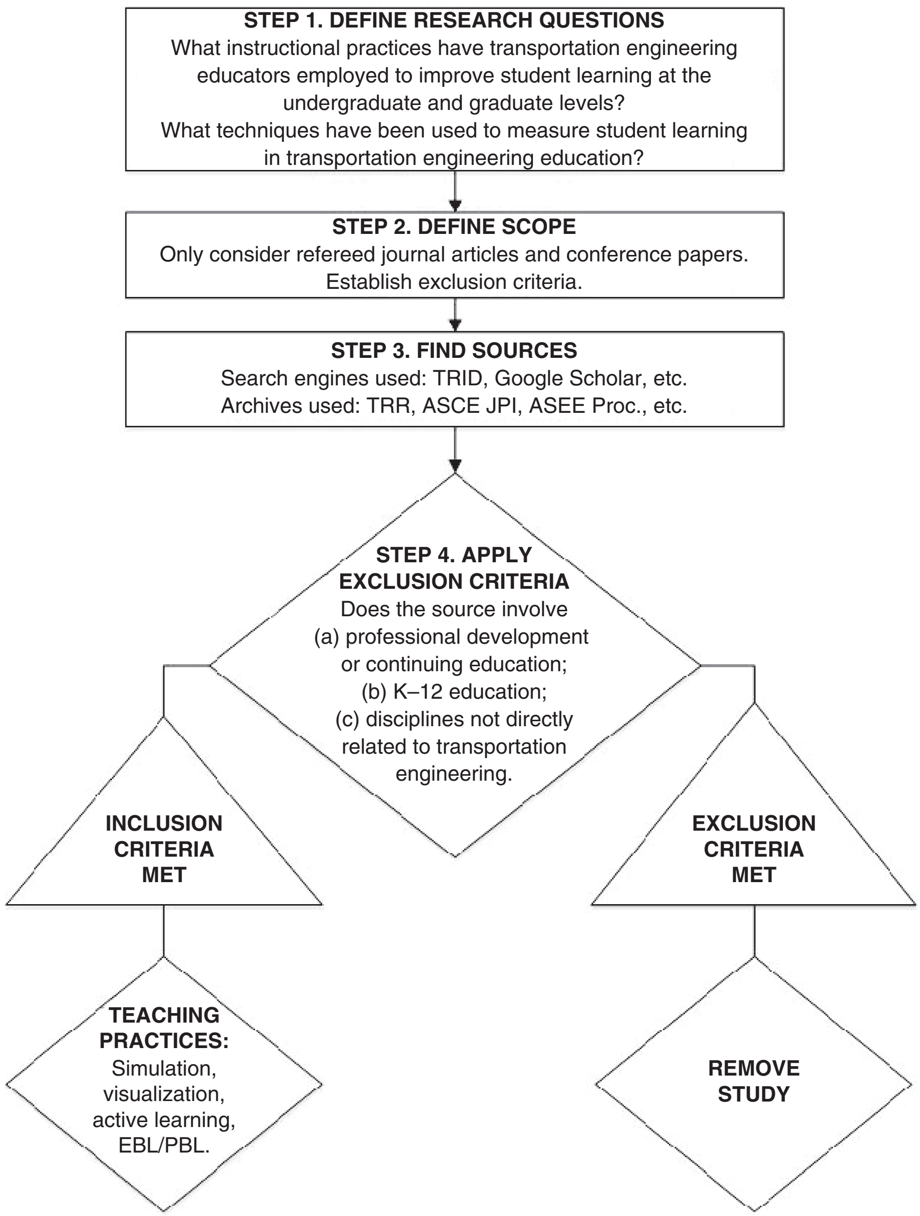

FIGURE 1 Systematic literature review process (K–12 = kindergarten through 12th grade; EBL = experience-based learning; PBL = problem-based learning).

broadly accessible to the transportation education community and intellectually rigorous.

A variety of search engines [Transportation Research International Database (TRID), Google Scholar, etc.], digital archives, and article reference lists were examined for relevant articles:

- *ASCE Journal of Professional Issues in Engineering Education and Practice:* http://ascelibrary.org/journal/jpepe3,
- *ASEE Annual Conference Proceedings:* http://www.asee.org/search/proceedings,
- *European Journal of Engineering Education:* http://www.tandfonline.com/toc/ceee20/current#.VBqT7fldWSo,
- Google Scholar: http://scholar.google.com,
- Web of Science (Thomson Reuters): http://wokinfo.com/,
- *International Journal of Engineering Education:* http://www.ijee.ie/,
- *ITE Journal* and Annual Meetings: http://www.ite.org/library/,
- *Journal of Engineering Education:* http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)2168-9830,
- Transportation Research International Documentation (TRID): http://trid.trb.org/, and
- Frontiers in Education Conference Proceedings: http://erm.asee.org/frontiers.html.

In each archive and reference list, numerous combinations of search terms were used:

- Education,
- Instruction,
- Instructional practices,
- Traffic,
- Transport,
- Transportation,
- Transportation curriculum,
- Transportation education,
- Transportation engineering curriculum, and
- Transportation engineering education curriculum.

Criteria for Inclusion or Exclusion

From the research questions, criteria were developed for including relevant sources and excluding those outside of the scope.

Specifically, the focus is on collegiate undergraduate and graduate transportation education. Therefore, articles focused on prekindergarten through 12th grade education, informal education, professional development, and continuing education were excluded. Articles focused on other subdisciplines of civil engineering also were excluded.

Within this scope, articles that focused on teaching and assessment of evidence-based instructional practices were included. Teaching practices include the use of active-learning principles, simulation, visualization, other technologies, and other types of innovations.

RESULTS

The results section is organized into three categories: a description of the final article database, an examination of papers focused on instructional practices, and an examination of how papers in the database measured the efficacy of novel instructional practices on the improvement of student learning. Manuscripts were first reviewed by each researcher independently and then discussed by the researchers as a group, so that the interpretations of articles represent the collective interpretation of all four researchers.

Final Article Database

After exclusion criteria were applied, 46 articles (20 from refereed journals and 26 from refereed conferences) were included in the database for further analysis in this paper. Journal articles were sourced from the *Transportation Research Record: Journal of the Transportation Research Board* (TRR), the ASCE *Journal of Professional Issues in Engineering Education and Practice* (ASCE JPI), and the *European Journal of Engineering Education* (EJEE). Conference proceedings were sourced from the American Society for Engineering Education annual conference (ASEE Proc.). The *2013 Journal Citation Report* lists the impact factor for TRR as 0.556 and for the ASCE JPI as 0.716. No impact factors for the remaining journals and conference proceedings are available (*6*). Articles in the database were published between 1999 and 2014 (Figure 2).

A visual inspection of the publication frequency over time indicates a generally positively increasing trend. This evidence suggests that scholarly work in transportation engineering education is increasing in importance as well as quantity. In the publications included for analysis, the average number of authors was 3.3 (median three), with a minimum of one and a maximum of nine authors (excluding committee written publications); the average number of citations in these publications was 18 (median 20), with a minimum of zero and a maximum of 36 citations. This work is collaborative and grounded in the literature.

Instructional Practices Developed

Transportation engineering educators have been publishing scholarly work that describes creative instructional practices for transportation engineering education for at least the past 15 years. These practices include tools for simulation and visualization, problem-based learning (PBL), and other types of active learning.

Simulation

With increases in computing capabilities, simulation has become more common in transportation engineering. The benefits of simulation—the ability to explore what-if scenarios and system response to changing parameters—offer opportunities for conceptual learning. Chen and Levinson describe the benefits of incorporating simulation into an elective senior or graduate course on transportation systems analysis as providing students with (*a*) experiences akin to real-world experiential learning, (*b*) opportunities to learn by doing, (*c*) an interactive learning environment with immediate feedback, (*d*) an opportunity to experience an alternative teaching method that may better match a student's learning style, (*e*) an opportunity to move toward higher levels of cognitive development, and (*f*) increased motivation (*7*).

Liao et al. reported on the development of an Internet-based traffic simulator that was demonstrated in an undergraduate transportation engineering course (*8*). The researchers implemented a laboratory module in which students were asked to use the simulator to develop

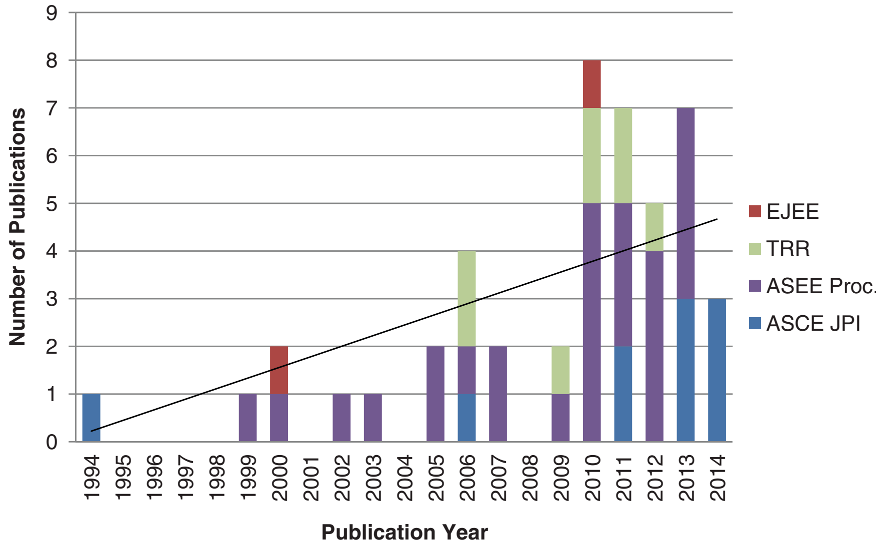

FIGURE 2 Frequency of refereed journal and conference publications by year.

signal timing plans, and they collected feedback from the students. They do not describe the expected or observed results.

Researchers have developed a suite of simulation tools for use in the typical undergraduate introduction to transportation engineering course (*8–11*). Their two primary hypotheses are that (*a*) "the simulation modules will improve student understanding of critical concepts in transportation engineering and lead to students learning better than they would in a course that does not use these simulation tools," and (*b*) "the simulation modules will enhance student motivation toward the transportation engineering field and will improve student retention" (*9*). This group of tools is collectively named STREET: Simulating Transportation for Realistic Engineering Education and Training; the individual tools and their assessment results, as reported in the literature, follow:

- Agent-based demand and assignment model (ADAM). Zhu et al. describe ADAM as a model in which each traveler adjusts destination and route choices until system equilibrium is reached (*10*). The authors concluded that students who used ADAM in a required undergraduate (junior year) introduction to transportation engineering class "improved their understanding of the transportation planning process and were more likely to use better judgment regarding analysis of transportation projects" (*10*).
- Online application of signalized intersection simulation. This tool allows a remote connection to a traffic signal controller; it enables students to implement and test their signal timing plans through computer animation. The authors do not report results of implementation (*10*).
- Roadway online application for design (ROAD). Liao and Levinson explain that ROAD enables students to design a highway alignment digitally using a contour map as a base (*11*). A survey to measure motivation, ease of use, and enjoyment of the learning experience was administered after students completed a project using ROAD as a lab module in an undergraduate (junior year) introduction to transportation engineering class, with results ranging from 3.04 to 3.60 on a scale of 1 to 5, with 5 being the most positive.
- Simulator of network growth. According to Chen and Levinson (*7*) and Zhu et al. (*10*), this tool is a bottom-up simulation of transportation network growth in which students can explore the relationships between link speed, land use, travel demand, and costs. An experimental evaluation of an elective senior or graduate class in transportation systems analysis revealed that use of the simulator improved student performance on some learning outcomes. However, issues with software and course design limited its effectiveness.

Luken et al. developed a simulation course module on airline operations for an elective undergraduate or graduate class on airports and freight (*12*). Students used the AIRLINE online simulation to understand business and operations decisions. Student survey results were positive and instructor evaluations of student work reflected learning gains.

Fang and Pines describe a project in which students developed their own simulation tools as a service-based learning project in an elective senior or graduate transportation engineering course (*13*). Students began development of their simulation tools with simple spreadsheet-based simulation models of stop-controlled intersections and then moved to the use of CORSIM and VISSIM models. Final solutions were presented to the agency staff involved with those projects, and qualitative student feedback was generally positive.

Visualization

Although transportation engineering students have significant personal experience as transportation system users, they may lack a system-level perspective, especially in the areas of traffic signal timing and network topologies. Researchers have developed visualization tools to address this void.

Brennan et al. describe a series of visualizations developed to help students understand the relationships between signal operation and vehicle progression for coordinated signal operation; however, the effectiveness of the visualizations is not discussed in the paper (*14*).

Brown et al. evaluated traffic signal timing activities that involve animation in an elective senior undergraduate course on traffic systems design (*15*). The evaluation used clinical interviews with students to understand impacts on student understanding and reasoning through the framework of conceptual change. The results show that students who used the animations had improved conceptual understanding of three of five concepts, as compared with students who did not use the animations.

Sun et al. describe the use of a virtual city called Sooner City to introduce engineering and design concepts across the curriculum; by the end of the 4-year program, each student has built a city (*16*). First-year students in the required introduction to engineering course are asked to begin work on their roadway network for Sooner City, with the dual purpose of visualizing the problem and learning traffic engineering concepts. From student perceptions of the experience, the use of the Sooner City visualization tool was effective in improving learning. The student responses showed the greatest improvement in being able to visualize the problem they were asked to solve.

Bertini et al. developed a handheld device to collect transportation data such as position over time, feature location, and vehicle and pedestrian counts that could be incorporated into classroom and lab activities (*17*). Collected data were then imported into spreadsheets and geographic information systems (GISs) for visualization. System effectiveness was not discussed.

Experience-Based Learning and PBL

Several PBL transportation activities have been described in the literature. Ahern discusses the integration of PBL exercises into junior and senior undergraduate transportation electives (*18*). One activity was incorporated in a transportation policy class, and two were included in a transportation modeling and traffic engineering class, both with positive feedback from faculty. Fini and Mellat-Parast describe a semester-long pavement design project that they developed and implemented in a required undergraduate transportation engineering course (*19*). Before-and-after questionnaires showed student responses to the approach were positive and that grades were higher than in a semester in which the PBL approach was not used. López-Querol et al. present a PBL approach to a required undergraduate transportation geotechnics and pavement engineering class and conclude that, on the basis of grades and pre- and post-class surveys, students are more satisfied and perform better with the PBL approach (*20*).

The earliest paper describes a transportation capstone experience during the senior year that was developed in response to changes in accreditation requirements in the early 1990s (*21*). Schoon explains that the course used a large-scale, open-ended design problem. Evaluations at the end of the course indicated a need for better organization, but, overall, the students found the experience acceptable.

Melin et al. redesigned an elective undergraduate introduction to transportation engineering course anchored by an experience-based learning exercise that accounted for approximately 60% of the course (*22*). The experience-based portion of the course included two-lane road design and construction, pavement design, maintenance, and repair, and earthwork operations. The authors reported the need for evaluation of outcomes in the future.

A study by Nicholas et al. sought to use real-world problems to supplement content in transportation and transportation structure design projects (*23*). The authors developed a course manual that included sections on MicroStation basics and the application of MicroStation in highway and bridge design. The course concludes with a final project that uses all of the skills learned within the three modules. Student feedback was positive.

Bandyopadhyay et al. describe community-based projects in which students conducted a case study of Route 101 traffic issues in New York. Real-world data were used to provide analysis and recommendations to a community planning board (*24*). These projects were conducted outside of a formal class. Evaluation results were not reported.

The impacts of a change from traditional lecture to project-based learning in a required junior introductory transportation engineering course were assessed by Hamoush et al. They used student questionnaires to capture changes along five learning dimensions from one term to the next (*25*). A highway and pavement design project was used throughout the term (in the project-based approach) to teach the related concepts. Increases were reported in four of five surveyed areas (higher-order cognitive domain of learning, self-efficacy, ease of learning, and impact on teamwork); the increase on ease of learning was statistically significant. The average grade increased, but the increase was not statistically significant. The researchers concluded that the project-based approach improved student learning.

Sun and Ritchie implemented PBL as a result of a partnership between the university and public agencies in which state-of-the practice methods and tools were introduced in an undergraduate traffic control course and laboratory experiences that were based on real-world transportation networks (*26*). Practitioners also provided input into the course curriculum. Student feedback on the 2-year experiment was positive. Similarly, Murad added team-oriented projects to a required junior transportation lab attached to a general transportation course that introduced open-ended problems (*27*). The introduction of the design problem required expanded course content to accommodate the scope of the project. Student surveys indicated that the lab experience was valuable.

Rose described the introduction of a "simulated consulting" project as an element of an undergraduate senior-level elective in transportation planning (*28*). The four-phase project included preliminary planning, data collection, coding and sharing of the data, and analysis and reporting. Students worked in teams of two or three to design travel surveys for bicyclists including demographic data, origin–destination data, trip purpose, and so forth. The influence of the project on student learning was not discussed.

Student perceptions of a case-based team learning approach used in an introductory transportation engineering course were examined by Nambisan (*29*). The class was divided into teams of two or three students; each team was assigned a transportation improvement project to develop during the semester. In each class period, a new set of groups was created to execute active-learning tasks during class. For the term-length project teams, students completed a survey of their perceptions on 10 team dynamics metrics and four dimensions of team performance. Key findings were that the combination of team-learning strategies and the case-based approach achieve higher levels of learning and that students generally favored this approach over more traditional methods.

Other Active Learning

Active learning engages students in ways beyond listening and can range from answering instructor questions to group problem solving (*30*). In addition to the examples of PBL described in the previous section, a number of examples of transportation-related active-learning modules and activities are available in the literature.

Kyte et al. describe some of the benefits of student-centered learning and examine curriculum development under such a model (*31*). Specifically, they describe and evaluate the *Highway Capacity Manual Applications Guide, Mobile Signal Timing Training,* and the *Transportation Education Development Pilot Project* on the basis of learning-centered curriculum development approaches. All three curricula were found to have clear learning outcomes and to support student assessment and critical thinking, but specific details about implementation were not included in the paper. In the same vein, Bill et al. present a set of learning outcomes and knowledge tables to support development of active-learning activities (*32*). Learning outcomes and knowledge tables were then used to restructure content of the required junior introductory transportation course at three universities, and changes in students' perceptions about the transportation profession were tracked over the semester (*33*).

Bham et al. developed and evaluated a GIS laboratory module for transportation safety in a required undergraduate introductory transportation engineering class (*34, 35, 37*). The laboratory included three tasks: a self-paced ArcGIS tutorial using a simplified crash database, a transfer task using a field-based data set, and a synthesis task to document findings. Their goals were "to evaluate, from students' perspective, to what degree the GIS laboratory was a useful learning tool for a civil engineer undergraduate in a transportation engineering course." From qualitative and quantitative evaluation, the authors concluded that the GIS laboratory facilitated student learning about traffic safety and helped students connect the concepts to engineering practice. Another related article noted that the GIS laboratory experience scored slightly lower than the lecture component of the course with respect to where students learned information; this result was likely because early versions needed adjustments in pace (*36*). The self-learned GIS laboratory used progressive scaffolding in which instructions are provided and students have the option to move forward with the lab or watch more in-depth video instructions. Student feedback on this feature was positive. Further, it was determined that student performance was improved by anchoring the lab in a 20-min transportation safety lecture (*35*). Sixteen of 27 students found the laboratory interesting, useful, realistic, or well-supported by the online tutorial; of these 16 students, 10 participated in the treatment group that included the anchoring safety lecture (*35*).

Another aspect of this study focused on changes in self-efficacy and perceived difficulty of material when the GIS lab component of the course was shifted from a separate stand-alone module to an integrated design project (*37*). On a nine-point scale, the average score on self-efficacy increased from 3.4 (stand-alone model) to 3.9 (integrated with design project), whereas perceived difficulty decreased from 5.8 to 4.3. However, an explanatory model was able to account for only 24% of the performance differences.

The use of threshold concepts, which involve the development of concept maps to allow for integrative and transformative shifts in student understanding, was applied to strengthen student understanding of the sequence of steps, and the interactions among them, in the development of a highway horizontal alignment in an introductory transportation engineering class of junior and seniors (*38*). The integrativity (realization of connections between steps not previously known) and transformativity (conceptual and ontological shifts in understanding) were demonstrated in reflective assessments made by many of the students in the class.

An interrupted case method, in which increasing details and context of a particular scenario are provided to students over time, was implemented by Brooks et al. as a means of teaching ethics in an undergraduate transportation engineering and systems management course and in a graduate transportation engineering course (*39–41*). Brooks et al. distributed the problem details in four increments separated by 3 weeks for active reflection. A 19% improvement in overall undergraduate student transportation engineering grades occurred between the treatment and control cases, and a 15.3% improvement in overall graduate student grades occurred between the treatment and control cases.

Mehta developed a variety of in-class activities for a required and an elective introductory transportation class (*42–44*). Mehta incorporated active problem solving into every class period (*42*); he also relied on the *Highway Capacity Manual* as a primary course text (*43*). In both cases, student surveys showed satisfaction. Mehta's subsequent paper (*44*) describes faculty assessment of student skills according to a rubric developed for the Accreditation Board for Engineering and Technology; again, the methods were considered useful.

Smadi and Akili describe briefly homework and project activities developed for an asset management course; the authors do not provide an assessment of the activities (*45*). The authors do argue that active learning and engagement-based teaching practices are critical in course work focused on asset management.

Prado da Silva et al. tested a progressive process of moving from course learning outcomes to specification of teaching–learning methods, to development of active-learning exercises, to the evaluation of course learning outcomes in a regularly offered undergraduate planning and analysis of transport systems class (*46*). Techniques used in this progressive process include a computer-based concept mapping tool, Index of Learning Styles, and the Keirsey Temperament Sorter for forming student teams. Minute papers, constant questioning, and teamwork exercises were used to stimulate student participation. One of the most positive outcomes from the effort was the use of concept maps, created by the students three times during the course to assess the progression of student learning. Half of the students showed strong improvement in their conceptual mapping and another 31% had moderate improvement (*46*). Student evaluations of the course were high.

Measurement of Student Learning

In the 46 papers reviewed that focused on instructional practices in transportation engineering education, student learning is addressed to varying degrees; in some cases, it is not addressed at all. Measurement techniques, in descending order of prevalence in the literature, include surveys, in-person interviews, direct assessment of student work, and concept maps. Ideally, the selection of a technique to measure student learning is guided by the particular learning objectives of concern, but the mapping of measurement technique to learning objectives was rare in the articles examined.

Surveys were used to measure student learning in 15 of the studies considered in this review. The most common approach included a pre- and postcourse survey (*7–9, 34, 35*). In this design, the precourse survey was typically used to collect demographic or confounding information on the students and baseline knowledge of the topic area of concern. The postcourse survey often collected self-reported performance data. Particularly useful precourse survey designs included additional information on student learning styles (*7*). These surveys were commonly applied to both control and treatment groups randomly selected from the same class or from two separate classes in different semesters (*7, 10*). Alternatively, Hurwitz et al. (*47*) and Jannat et al. (*48*) used a longitudinal survey design that included pre-, post- and 6-month surveys, and Liao and Levinson (*11*) and Bham et al. (*34*) used pre- and postcourse surveys for several years with subsequent cohorts of students and a particular intervention. The inclusion of additional data points can significantly increase confidence in the results of such surveys. Several studies used a single postcourse survey for data acquisition (*12, 13, 16, 19, 36*). López-Querol et al. also used postcourse surveys but compared the results of a control group and an experimental group (*20*). The lack of precourse survey or baseline data poses a challenge in the assessment of the impact of a particular intervention. Alternatively, Mehta used a survey rubric for faculty members to evaluate student progress (*44*). Open-ended survey questions were used by Bham et al. to better assess student perceptions of a GIS laboratory (*35*).

In-person interviews have been used as a means of determining differences in the conceptual understanding and ways of thinking in control and treatment groups before and after particular instructional practices (*15*); as a way to compare two different groups, as Davis et al. did with instructors and engineers (*49*); or by randomly selecting representative students from a population, as demonstrated by Andrews et al. (*50*). Interviews also were used to analyze traffic signal misconceptions across novice students, expert students, and practicing engineers to determine conceptual differences between those groups (*51, 52*).

Direct assessment of student work has been used as a means of determining the impact of student performance in particular content areas. Quizzes were used as a stand-alone activity by Zhu et al. (*10*) to measure student performance on travel demand modeling and as an element of a follow-up survey by Bham et al. (*34, 35*) to assess retention of basic traffic safety issues examined in GIS software. Chen and Levinson used questions from a final exam on four-step traffic demand modeling as a measure of student performance (*7*).

Concept maps were uniquely applied by Prado da Silva et al. longitudinally at the beginning of class, immediately before the intervention, and after completing a project associated with the intervention (*46*). The concept maps were analyzed to assess the conceptual knowledge and quality of the conceptual relationships developed by the students over time.

DISCUSSION OF RESULTS

From the analytic review of literature, it is apparent that interest in transportation engineering education is increasing, as indicated by the strong upward trend in the number of articles published by year (Figure 2). This trend also coincides with direct efforts to build and strengthen the community of practice for transportation engineering educators (*1, 47, 53*). Presumably, the authors of these articles want not only to document their efforts but also to inspire others to adopt and adapt the effective teaching practices they describe.

A considerable number of innovative methods and tools that would be of interest to transportation educators was found in the instructional methods literature. These methods include simulation and visualization, PBL, and other types of active-learning approaches. Of these, the focus most often was on active-learning approaches. The articles describing these efforts can provide a starting point for educators looking to implement new techniques in the classroom and also can stimulate ideas for new tools or approaches.

The tools and methods discussed in these articles usually were the result of individual institutions using research funding to try new techniques. Many of these articles referenced educational literature and occasionally referenced engineering education literature, but only rarely did they reference other transportation engineering educational efforts beyond the work done at that institution. Greater dissemination of ideas, and ultimately adoption of best practices, across institutional boundaries will be necessary to create a stronger community of transportation engineering education practice. Efforts by the authors to strengthen this community have been documented, but more is needed (*47, 53*). The literature summarized in this article indicates that appropriate innovative classroom practices are well received by students and that the impact on student learning is generally positive. It also was found that most of the reported assessments relied heavily on indirect measurement, such as the use of student opinion surveys; however, a few efforts performed direct assessment through the use of control groups, exam and quiz questions, and concept mapping. The student surveys measure engagement and students' perception of their learning, whereas the direct assessment measures actual student learning. To stimulate wider adoption of innovative teaching practices in transportation engineering, more direct assessment of student learning will be necessary.

Barriers to more widespread adoption of innovative teaching practices include lack of best practices, lessons learned, and advice for those wishing to adopt the practices described, as well as limited data on the efficacy of these practices in student learning.

The development and documentation of novel instructional practices is both resource- and time-intensive. The impact of this investment is significantly increased if those practices can be widely adopted by other faculty teaching similar content. This adoption is more likely to happen if the efficacy of the instructional practices in question has been rigorously established. In this context, one of the most meaningful measures of teaching efficacy is the potential to improve student learning. The literature reviewed describes the teaching practices adopted, and in many cases it describes challenges the authors faced in development and implementation. However, few articles explicitly address the needs of someone wishing to adopt the innovation described in the work. Although the documented spread of these practices is low, it is likely that some of these innovations have been adopted, but not reported, by other faculty members.

A variety of opportunities and resources exist that could promote the dissemination and adoption of evidence-based instructional practices in transportation engineering education. For example, communities of practice can informally share best practices. Such interactions can be facilitated by organizations such as ASCE, ASEE, ITE, and TRB. These organizations publish journals and conference proceedings that enable transportation engineering educators to share work on innovative teaching practices. Increased understanding of the value of such work and commensurate recognition in faculty reward structures also has the potential to stimulate the development of such a community. For work that is intended to demonstrate improved student learning, peer reviewers should require that authors demonstrate the application of best practices in its measurement.

The education literature includes a number of excellent examples of best practices for measuring student learning (*54–57*). For example, Novak, considered the founder of concept and knowledge maps, documents their appropriate use as instructional and assessment techniques (*54*). Think-aloud interviews have been used in a variety of applications, and Leighton focuses on the application of think-aloud interviews for education measurement (*55*). Hestenes et al. documented the development and implementation of the Force Concept Inventory, the first concept inventory, which consists of a collection of multiple-choice questions (*56*). Each question is concerned with only one concept and each wrong answer is based on commonly held student misconceptions. Dozens of concept inventories in other disciplines have been developed on the basis of the Force Concept Inventory. Angelo and Cross documented more than 100 additional assessment techniques, including the minute paper, approximate analogy, and muddiest point paper (*57*).

Another example of relevant work from the broader engineering education field is a recent article by Ambrose for the National Academy of Engineering that highlighted the following six findings from previous engineering education research that should be integrated into curricula (*58*):

- Context and integration across courses promotes transfer of knowledge and skills to new contexts;
- Early exposure to engineering and engineers lays the foundation for future learning;
- Timely, meaningful engagement promotes deep learning;
- Opportunities for reflection connect thinking and doing;
- Development of metacognitive abilities fosters lifelong learning skills; and
- Authentic experiential learning opportunities put theory into practice.

Ambrose makes the particularly compelling point that much is known from previous research about what works in engineering education, and it is time to begin more meaningful implementation.

A useful resource, although not specific to engineering, is the What Works Clearinghouse website managed by the Institute of Education Science (*59*). This clearinghouse provides well-reviewed research results on educational practices and would be useful to transportation engineering educators for providing both research results to justify proposed classroom practices and planning methods for assessing student learning. A second resource is the ciHUB (https://cihub.org/), which is supported by the National Science Foundation and operated by Purdue University (*60*). Among its many functions, ciHUB provides a platform for archiving and disseminating concept inventories, including several in engineering.

Finally, the 2009 article by Chi is a good resource for active learning, both for its framework for classifying learning activities into passive, active, constructive, and interactive and for its extensive list of active learning references (*30*).

CONCLUSIONS

Transportation engineering education is an emerging field of scholarly inquiry that is, by its nature, inherently complex and interdisciplinary. As with all such fields, periodic analytic literature reviews are critically important for collecting, synthesizing, and interpreting the existing body of knowledge, as well as identifying gaps and opportunities. This analytical literature review focuses on innovative teaching practices and techniques for measuring student learning in transportation engineering education.

The review of innovative instructional practices found the following:

- A variety of simulation, visualization, concept mapping, and other active-learning techniques has been applied to myriad topics in transportation engineering.
- The majority of this work has been developed and implemented by a researcher or a team of researchers at a single institution, with little evidence that dissemination efforts have resulted in wider adoption of these practices.
- There is a need for work that promotes the adoption of those innovative practices that have been shown to be effective.

The review of techniques for measuring student learning found the following:

- The measurement of student learning has been assessed through the use of surveys, including open-ended survey questions; in-person interviews; the direct assessment of student work; and concept maps.
- The most compelling evaluations of student learning include both qualitative and quantitative elements and triangulate student performance across multiple measurement techniques.
- There is a clear need to consider and more rigorously evaluate the student learning that results from novel instructional practices in transportation engineering education.

The transportation engineering education literature at present is not well-developed enough to support recommendations of best practices from within this literature. However, the transportation engineering education literature, when combined with the broader engineering education research literature, some of which is summarized in this paper, suggests that active learning activities can be effective in improving student learning. Further, an opportunity exists to map the state of the practice in transportation engineering education instructional practices in ways that go beyond a literature review.

This paper also documents the process that was used to compile all of the literature on this topic into a single source. A review of this type should be done periodically to facilitate access to the body of literature and the drawing of broader meta-level conclusions from the research, as is more common practice in disciplines with well-established educational research communities, such as physiology or medicine. Further, it serves as a model for researchers who want to conduct a similar effort in fields with similar characteristics.

This analytical literature review serves as a resource for transportation engineering educators to quickly identify a variety of resources, detailing techniques that can be implemented in the classroom to improve the quality of student learning. This resource should be of interest to all transportation engineering educators, both those who plan to document related work publicly and those who simply wish to apply the work of others. The authors hope this resource will inspire further development of new and innovative techniques in the field of transportation engineering education.

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