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An evaluation of the effectiveness of transportation engineering instruction
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The state of transportation education and engineering training has been a topic of discussion since 1961 with the publication of Jane Jacobs' *The Death and Life of Great American Cities*. In this seminal work, Jacobs argues that the transportation engineer's emphasis of the technical and quantitative (e.g. traffic flow) over the qualitative is responsible for the destruction of the urban fabric. Jacobs contends that engineers are taught to focus on the quantitative and technical at the expense of learning about the liberal arts, including history, sociology, and psychology, resulting in a technically superior, but boring and sterile, infrastructure whose very blandness and utility is destroying the urban character. Jacobs' work was subsequently used to justify the urban freeway revolts that swept the country in the 1960s and 1970s, and is used by many in the planning profession.

By the middle of the 1970s and into the 1980s, the transportation engineering profession was still plagued by the problem that Jacobs noted in 1961 – an overemphasis on the quantitative at the expense of the quantitative. In other words, transportation engineers were still focused on the mathematics and the efficiency and had a very limited worldview. Gurin (1976) noted how transportation engineers should heed the lessons of the failed urban renewal policies of the previous decade with the focus on technical superiority and efficiency, and cautioned that the technically superior answer may not be the correct answer. Flyvbjerg (1984) expressed alarm as to the regression of the transportation engineers back to focusing strictly on the technical, with Loukissas and Mace (1984). This regression could be a result of the changes in the American political climate as a whole, with the election of the conservative Ronald Reagan to the presidency in 1980 marking a paradigm shift from liberal arts to business and numbers. This paradigm shift also resulted in governments emphasizing benefits versus costs above all else to justify expenditures on transportation projects to an electorate eager for tax cuts, as well as for cover from the propagandists who convinced the public that the government is too large and wasteful. Those receiving an engineering education at this time learned about the mathematical and technical fundamentals and little else, with liberal arts being relegated to the realm of electives. This is the current structure of the transportation curriculum at Wayne State, a university that has seen its budget cut repeatedly by a conservative, tax-cutting legislature that has consistently convinced the electorate that the government is excessive and wasteful. Wayne State is not unique; this phenomenon is occurring at universities in conservative states across the country.

This narrowing of the focus of transportation engineers has created some problems with respect to educating them. In a study of a transportation engineering course, Mladenovic, Mangaroska, and Abbas (2014) correctly noted that the variety of students taking a typical transportation course representing a variety of worldviews and interests, and thus a narrow and limited curriculum does a disservice to those students who are not specifically transportation engineers. At Wayne State, transportation engineering students represent a minority of students in the transportation engineering class, with the remainder of the students representing the various branches of Civil and Environmental engineering (construction, structures, etc.) as well as other types of engineering, such as Industrial Engineering. Such diversity makes it challenging to create a syllabus that teaches the fundamentals of transportation while simultaneous not favoring one set of students over the others resulting in disengagement. Hurwitz, Brown, Islam, Daratha and Kyte (2014) compared the fundamental knowledge of transportation engineers with respect to time from taking courses in transportation, and determined that as time elapses, the less knowledge an engineer has, indicating that students are not actually absorbing the information they are taught, but memorizing it for the short term. This loss of knowledge over time, as many practicing transportation engineers have a complete lack of understanding of even the basic concepts, and thus make erroneous policy decisions that can have significantly detrimental, if not fatal, consequences. Bad transportation decisions not only can destroy communities, they can destroy lives, so it is imperative that every effort be made to ensure that engineers understand the fundamentals, including proper decision making skills.

The transportation engineering course at Wayne State was divided into four major components- lectures, homework, projects, and tests. In addition, readings were assigned, as well as extra credit learning opportunities outside the class. Felder and Silverman (1988) make several recommendations as to the most effective ways to teach an engineering class, and those methods, or derivatives thereof, were used throughout the course. The final examination was a multiple choice examination written in such a way as to test the effectiveness of these strategies and to determine the learning strengths and deficiencies of the students. Information was conveyed verbally, through the use of power point presentations, in a narrative format, through the use of examples, visually, through written e-mail correspondence, and through homework assignments and projects. Of the 28 class periods available, 23 were dedicated to introducing new topics, 3 were review periods, 1 was for the presentation of the semester project, and one was for the midterm examination.

Lectures

As previously stated, 23 different topics were presented. For the first 21 topics, a power point slide presentation was created, with detailed notes detailing or explaining the concepts. A free digital textbook, Fundamentals of Transportation, was provided, and the topics were presented in the order they were presented in the textbook. The textbook is divided into two parts – planning concepts and design and operational concepts. Of the 23 topics, four were not covered in the text, with one, “Parking”, presented between the two halves of the book as a bridge (as it contains elements of both planning and design), and the other three, “Pavements, drainage, and lighting”, “Traffic control devices”, and “Work zones”, presented at the end of the semester. The last two topics were presented using a Kodachrome slide slow and an overhead slide show, with notes provided for each. All lecture material were posted on the class website in pdf format for viewing by the students prior to class. Throughout the semester, students were encouraged to print and bind the lecture material for easy reference. To assist the students in organizing the materials, the slides for each topic have a unique background that relates, either directly or indirectly, to the topic being presented, with the first slide for most of the topics explaining the connection between the background and the topic. Topics ranged from 17 to 65 slides, depending on the topic. Students were expected to read the accompanying readings on the topic prior to class to be able to engage the instructor in the rhetorical questions asked in the notes.

The “Traffic Control Devices” lecture consisted of 150 slides covering various examples of traffic control devices and the results of improper traffic control. Accompanying this particular presentation was a brief narrative of the major points of the presentation. In addition to the 23 topics, midway through the course an additional presentation consisting of examples of some of the concepts of traffic flow and parking was presented and posted. (In addition, examples were given in many of the lecture notes.) As mentioned, the final topical presentation, “Work zones”, consisted of overhead slides that were also published and posted in a digital format.

In addition to these lectures, other topics were discussed in several of the class sessions. These topics pertained to engineering ethics and engineering failures in design, maintenance, and operation. Appropriate articles were posted to the class website, along with questions relating to the material. Answers to the questions were typically submitted electronically for extra credit, with a follow up dialogue between the instructor and the student.

Homework

The original syllabus called for 10 homework assignments and 4 projects. Due to student complaints about the workload, one of the projects was dropped and replaced with two additional homework assignments. The homework assignments ran the gamut from simple to complex, and were designed to test the students' skills in geography, critical thinking, data interpretation, mathematics, design, technical writing, and code interpretation. The more complex problems tested more skills than the simpler ones. Of the twelve assignments, seven were design related, four were planning related, and one assessed the students' understanding of the concept of transportation. All assignments incorporated real world elements as part of the exercise to demonstrate how the knowledge is applied. For some of the assignments, there was no one correct answer, meaning how the student applied the concepts was entirely up to them, with these assignments evaluated on if the student chose the correct concepts and how well the selected concepts were applied. When possible, solutions were posted for the homework assignments on the class webpage, with detailed explanations of how those solutions were derived. For homework assignments where one or more students asked for help, examples were posted to provide guidance.

Projects

As previously mentioned, the original syllabus called for four projects – one to be worked individually, two to be worked collaboratively but final results written individually, and one to be a semester long class project. Due to student complaints about the quantity of coursework, one of the two collaborative projects was dropped and changed to two additional homework assignments. The individual project was a report on a specific freeway that was not built due to the freeway revolts. The collaborative project involved using existing parking, pedestrian, and traffic data from a small urban college, determining what patterns and problem exists, and making recommendations for changes. The group project entailed a corridor study for the feasibility and design of a freeway or tollway facility in the upper peninsula of Michigan, including a verbal presentation and a detailed written report.

An extra credit project was added for the benefit of those students who were interested in alternate assignments to correct point deficiencies. This extra credit project consisted of four options, of which a student could do as many as he or she desired. These options were: a gap study for vehicles downstream of a traffic signal; a queuing study at fast food restaurant drive through kiosks, with emphasis on locations with multiple parallel kiosks; a speed study verifying the correctness of posted speed limits; a detailed critique and evaluation of each of the topic "modules" of the course (other than the instructor). A majority of the students opted to partake in at least one of these extra credit projects.

Tests

There were two tests in the course- a midterm, covering the first thirteen topics, and a comprehensive final exam. Both tests were open book, open note, open computer tests. The first exam was a traditional problem-type examination, with partial credit given. The final exam consisted of 125 multiple choice problems, with each problem having five possible answers. Partial credit was not given for these problems. Of the 125 problems, 40 were from the first lectures, projects, homeworks, and the midterm, 80 were from work subsequent to the midterm, and 5 were miscellaneous problems from readings posted but not necessarily explicitly discussed. To reflect this breakout, the problems on the exam were not numbered sequentially from 1 to 125, but sequentially within each of these three series, with the three series mixed throughout. (Thus, a problem 40 could be followed by a 21, as the subsequent problems reflect the different series.) To randomize the answers, each answer was assigned a colored block with a block being pulled out of a bowl for each problem, with the selected block being the answer for the corresponding problem. The breakout of the answers is as follows:

For 20 problems, or 16 percent of the total, the correct answer was “a”
For 19 problems, or 15 percent, the correct answer was “b”
For 28 problems, or 22 percent, the correct answer was “c”
For 35 problems, or 28 percent, the correct answer was “d”
For 23 problems, or 18 percent, the correct answer was “e”

By completely randomizing the answer distribution (both in terms of placement and the quantity of each correct letter), a student who randomly selects one given letter for all answers is not guaranteed 25 correct answers; they may get more or less depending and the random “luck of the draw”. Furthermore, since many students theorize that certain letters (notably “a” and “c”) appear more, using this knowledge to try to guess the correct answer could be detrimental to success depending on what letter their theory says to use. Finally, a clever student cannot use a computer random number generator to recreate the answer pattern as no programmed mathematical algorithms were used.

ANALYSIS

The distribution of answers selected by the students did not match the actual distribution. The students’ answer distribution is as follows:

“a” was selected 22 percent of the time, 6 percent higher than actual
“b” was selected 17 percent of the time, 2 percent higher than actual
“c” was selected 24 percent of the time, 2 percent higher than actual
“d” was selected 22 percent of the time, 6 percent lower than actual
“e” was selected 14 percent of the time, 4 percent lower than actual

The actual answer distribution frequency is “d-c-e-a-b”; the students’ answer distribution frequency is “c-d-a-b-e”. (“d” was selected 1063 times, “a” was selected 1060 times.) Of the 125 questions, for 16 over 85% of the students answered correctly, for 61 between 50% and 85% of the students answered correctly, for 26 a plurality of students selected the correct answer, and for the remaining 22, a minority of students chose the correct answer. For all three series, the first two groups represent the majority, with a majority of students choosing the correct answer for 22 of the 40 old series questions, 52 of the 80 new series questions, and 3 of the 5 miscellaneous series questions. Comparing the old and new series, one can see the trend of decreasing expertise detected by Hurwitz et. al., except in a much more abbreviated time frame.

Ten of the 22 questions in which only a minority of the students answered correctly are from the series of questions covering the first half of the semester. In other words, this series represents 45 percent of this group but only 32 percent of all of the questions on the exam; thus it is grossly overrepresented. By contrast, the miscellaneous series represents 4 percent of this minority grouping and 4 percent of the total number of question, and the latter half of the semester series represents 50 percent of this group and 64 percent of the total number of questions. It may be reasonably concluded that students were not absorbing and retaining long term knowledge, merely memorizing facts for short term use to pass a class.

Given that the examination was open book, and many of these questions pertained to homework assignments, this lack of absorption is alarming. For example, one of these questions asked the least efficient type of public parking space. This information was covered in the slides, the notes, and examples. A similar question in this group involved calculating the number of parking spaces for a particular size lot with a particular land use, an exercise that was covered in one of the homework assignments. Questions that involved spatial relationships also fell in this group.

Analyzing the questions in this group and in the plurality group, as well as the questions in the majority correct groups, several commonalities emerge which can be useful for instructors, practitioners, and those who want to improve the overall quality of the profession:

1. *Repetitiveness is irrelevant to absorption of knowledge*. Many of the questions that were missed involved information that was repeated. On the other hand, some of the questions that were overwhelmingly answered correctly pertained to information that was only presented one time. Information that was presented as part of an anecdote was successfully retained and absorbed, whereas information that was presented in more traditional ways, even repeated multiple times, was not retained.

2. *Homework has questionable value in knowledge retention*. Many of the problems that were missed were from homework assignments. Although Felder and Silverman recommend collaboration, perhaps too much collaboration reduces the effectiveness of homework assignments. The homework assignments show indications of heavy collaboration, with the same errors showing up on homework submittals of multiple students. One problem with homework is that it is practically impossible for the instructor to know who actually did the work until tests are given. One of the problems taken from the homework had a pathetic four correct answers.

   Since the projects were more intense than the homework assignments, two of the questions related to the projects were answered correctly by a majority of the students. However, the project questions resulted in 21 out of 38 correct answers, which is low for the amount of work put into them. The third project related question, with the word “moose” substituted for “deer”, yielded nine correct answers. Either the students didn’t absorb the information they obtained with the project, or became confused with a simple word substitution. Either way, this is cause for concern.

3. *Students have difficulty performing more than one mathematical task*. For similar problems where one variation requires one simple calculation and the other more than one, the students performed poorly when requiring more than one step to solve the problem. Two of the parking problems required calculating the total number of spaces; one required one calculation, the other three. Students performed acceptably with the former. It wasn't just the parking problems; this phenomenon occurred with all problems requiring more than one step to solve. As engineering typically requires that a problem be solved with more than one step, this inability could severely hamper the ability of the students to achieve professional success, resulting in the alarming burnout seen among practitioners.

4. *Students have difficulty interpreting figures and tables*. Many of the problems where students performed poorly involved interpreting data from figures and tables. This is worrisome as many design standards are presented in either tabular or graphical form. The worst problem on the test had three correct answers; this was a vertical curve problem where the equations were presented graphically. Students have difficulty visualizing a solution.

5. *Examples are ineffective*. Many of the problems that were answered incorrectly had examples of how to solve a similar problem. This was especially true with the design related problems, most notably vertical and horizontal curves. Interestingly, students in their critiques suggested the use of even more examples to understand the material. This leads to the question – how many examples are needed? Some of the problems on which students performed the worst were accompanied by multiple examples, while some of the problems on which students performed the best did not have any examples at all.

6. *The more choices available, the worse the performance*. Problems where there are only one or two choices, the students performed the best. Beyond three possible choices, performance dropped. Problems where students had to choose the best option among viable options, with no clear choice, proved challenging and difficult.

7. *Students have difficulty interpreting codes and ordinances*. The MUTCD was the epitome of this difficulty, as several of the problems students got wrong involved the MUTCD. When the language of the MUTCD was rewritten in a less technical and more colloquial manner, the students excelled. The students understood some of the basic concepts of the MUTCD, most notably the difference between "shall", "should", and "may", but had difficulty interpreting it.

8. *Students have difficulty interpreting narratives*. Several of the problems that students missed involved retrieving the correct information from a narrative. One of these problems came directly from the narrative notes, and was answered correctly by only four students. This verifies what the instructor observed with students having difficulty understanding directions.

9. *Students have difficulty with geographic and spatial information*. One of the most spectacularly disappointing results was four students answering correctly a problem that was taken from the midterm with changes to the geographical references. This problem, the “longest-to-shortest” method, asked the students to determine which trips were the shortest in length. The trip data was listed in order from longest length to shortest length, yet students did not make this simple spatial connection. Other problems involving interpreting spatial data yielded similar poor results.

10. *Students have difficulty with units*. Being a class with both international and domestic students, the instructor used both the SI and US Customary units and nomenclatures. Many of the reference materials used used both sets of units as well, so it was imperative that the students have a firm grasp of units, and conversion between units. As conversions (even among the same measuring system) requires additional mathematical calculations, students performed poorer when a question required a conversion than when the same type of question did not.

CONCLUSION AND RECOMMENDATIONS

Given that this is a diagnostic analysis of one transportation engineering class at one university, the sample size is extremely limited and the results should be used with extreme caution. However, despite the small sample size, the results agree with the previous research and observations of transportation engineers, namely a narrow focus, loss of knowledge and skills over time, and a general inability for abstract thought and analysis (as epitomized by the use of detailed design “recipes”). Addressing these observations and improving the quality of engineering education is a win-win-win: a win for the students, who will have the necessary skills and knowledge to maximize success; a win for instructors, by allowing them the ability to pass on the valuable knowledge without being hindered and frustrated by lack of student success, which ultimately reflects poorly on the instructors’ teaching skills; a win for the public and private sectors who will be employing the students in their future endeavors, and who can spend more time and effort on improving their communities through engineering and less on training.

Since academia has the ultimate responsibility for training future engineers, academia has the duty to address these issues. Many of these problems can be mediated through changes in required coursework. Requiring courses in surveying and GIS will help solve the issues about spatial deficiency. Liberal arts courses in communication and philosophy help with the abstract narrative issues. A legal course will address the problems in interpreting codes and ordinances. A transportation lab would be more effective than homework or projects in learning and applying the concepts. Finally, in lieu of homework assignments, more frequent comprehensive testing may help address the knowledge retention issue.

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