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Application of Active Learning Techniques in Undergraduate Civil Engineering Curriculum

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Active Learning Applications in Undergraduate Civil Engineering Curriculum

Abstract

Engineering educators are charged with the responsibility of developing future engineers whom are prepared to lead societal change in the built environment. To best prepare engineering graduates to rise to the occasion of such complex demands necessitates use of new approaches in classroom instruction and innovative methods based on active learning concepts. This paper describes application of active learning techniques, predicated primarily on the use clicker quizzes, and additional student enrichment activities used to engage students, improve academic instruction, and enhance the learning environment. Instructional methods used in undergraduate civil engineering courses at The Citadel are presented and discussed. Active learning techniques and student enrichment activities include: clicker quizzes, in-class group activities, class examples, application of technology, hands-on field experiences, community service projects, and professional skills development. Student performance data and results from semester-long active learning applications are tabulated and analyzed to explore effectiveness and application insights. In addition, use of structured student enrichment activities are reviewed and tabulated with regard to purpose, use, relevance, and outcomes.

Vision for Civil Engineering Graduates

An emerging vision for the civil engineering profession is focused on student skills development to meet future infrastructure demands in establishing a sustainable world and raising the global quality of life. To meet increasing societal demands, civil engineers are required to be effective master builders, skillful stewards of the environment, innovators, managers of risk, and leaders of public policy[1,2]. These characteristics are especially relevant to graduates entering careers in engineering. Effective application of well-constructed scholarship of instruction techniques in higher education curriculum, play a valuable role in preparing engineering graduates to meet the high calling of these demands. Instructional methods that focus on active learning techniques, hands-on field experiences, service learning projects, and community service are recognized academic tools for equipping civil engineering graduates to serve as stewards of infrastructure, address complex construction objectives, and serve as leaders of public policy in the built and natural environmental.

Introduction

Far-reaching changes in curriculum enhancement and delivery of instructional materials are being implemented, evaluated and debated by engineering education leaders[3]. Considerable emphasis is being placed on enhanced student preparation and understanding of complex requirements in engineering design, through consistent application of appropriate teaching methods to achieve desired intellectual and analytical skills[4]. Upon graduation, students frequently encounter and are challenged to address ill-structured, open-ended problems. Historically, undergraduate engineering curriculums have not provided a well-scaffold academic foundation to prepare students to smoothly transition into a problem-based work environment, representative of professional practice[5].

Active learning techniques are becoming more and more prevalent in university classrooms within the U.S., and abroad. For example, active-based-learning curricula for undergraduate courses in traffic and highway engineering were developed at Worcester Polytechnic Institute[6]. The effectiveness of those techniques was tested using student performance and attitude data. It was shown that students performed better in written examinations and had slightly more positive attitudes at the end of class when compared with a controlled traditional class[6]. Additionally, a problem-based learning program was implemented in civil engineering at University of Limerick, Ireland[7], which provided a new learning experience for students that was well received[7]. Furthermore, a study conducted at Setubal Polytechnic Institute, Barreiro, Portugal showed that active learning techniques increase student engagement, class attendance and participation[8]. Active learning techniques such as clicker quizzes, Think-Pair-Share, PowerPoint jeopardies, one minute papers, group work, flipped classroom, peer surveys, mind-mapping, and visual webs are currently used at University of California at Berkley[9], Brigham Young University[10], University of Wisconsin-Madison[11], Utah State University[12], California State University[13], University of Minnesota[14], Indiana University Bloomington[15], Duke University[16] and numerous other universities, as well.

Use of clicker quizzes is an easily adopted form of active learning that is popular among higher education institutions. For instance, clicker quizzes were used in four courses at the University of South Carolina. Feedback from clicker use was positive from both students and faculty. Students agreed that clickers were beneficial in learning course content and faculty observed increase in class attendance and participation[17]. Furthermore, Martyn[18] conducted survey results to look at student perceptions of clicker use. The majority of students found clickers and class discussion helpful in their course content understanding and recommended that clickers be used again in the course. The impact of clicker quizzes on students and course instructors was studied by Eschenbarch, et al[19]. Clickers were concluded to make class more fun for both instructors and students. Professors were able to know their students better as individuals, gage how well students understood the class material, and receive positive feedback from university administrators and promotion and tenure committees.

This paper presents and discusses organization, assignments, perceptions, feedback, evaluation, and classroom applications using active learning techniques and enrichment activities to prepare students for professional practice in the field of civil engineering. Additionally, this paper describes how active learning techniques and enrichment activities are being integrated into the curriculum to provide students with the technical knowledge required to master course content and skills needed to understand the engineering profession's role in society. The paper explores and examines the effect of active learning techniques with a specific focus on application of clicker quizzes and as part of classroom instruction and engagement of student learning. Student performance and perception data on application of clicker quizzes for undergraduate courses in transportation engineering is analyzed and discussed.

Use of Clicker Quizzes for Active Learning

Clickers are wireless devices that work via radio frequency, allowing students to respond to multiple-choice questions through use of small handheld remote keypads. They are most

commonly used in large classroom settings to increase attendance and engage students in class participation. Professors can also evaluate what students have learned, activate prior knowledge gained from previous lectures, and facilitate class discussions on material covered during class. Clicker quizzes were incorporated into a transportation engineering course comprised of 46 students to encourage participation, prompt lively discussion, and support student comprehension of class subject material content. Clicker quizzes were administered during numerous class sessions to reinforce concepts gained from previously required reading assignments. Quizzes ranged from 3 to 27 multiple choice questions, with an average of quiz comprised of 14 questions. A total of eleven clicker quizzes, including a total of 158 questions, were given to students during the 2013 Spring semester. Table 1 summarizes number of students participating, number of quiz questions, and student average percent grade for each clicker quiz. Student participation varied from a low of 29 (63%) students to full class attendance of 46 (100%), and averaged 88 percent class participation across all eleven clicker quizzes. Analysis of performance data from eleven-clicker quizzes concentrates on two specific aspects of student performance including: 1.) Effect on facilitating informative small group discussion, and 2.) Possible informative trends correlating with final course grades.

Table 1 Summary of Clicker Quiz Participation and Performance

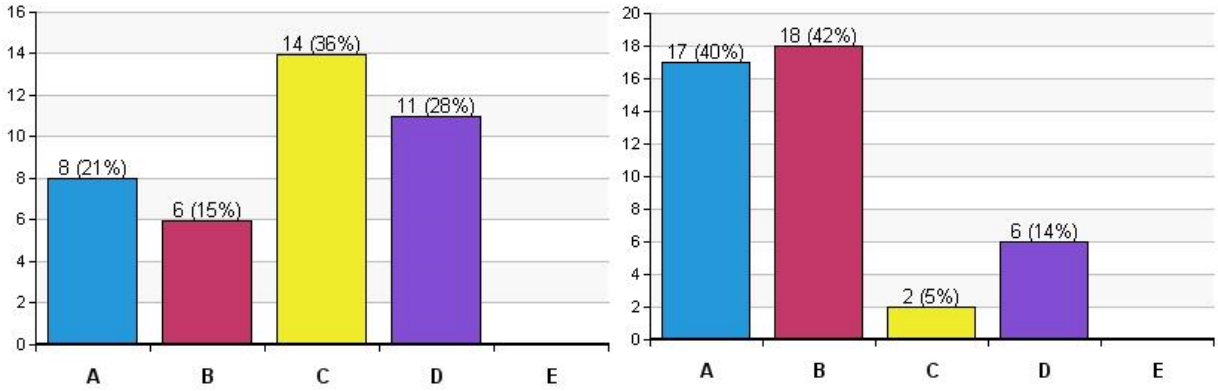
Clicker Quizzes	# of Students Participating[1]	# of Quiz Questions	Quiz Performance Average[2]
Quiz 1	41	7	89.2%
Quiz 2	39	13	81.1%
Quiz 3	46	15	79.4%
Quiz 4	46	27	82.4%
Quiz 5	43	7	87.0%
Quiz 6	41	16	87.3%
Quiz 7	46	22	82.6%
Quiz 8	29	11	79.5%
Quiz 9	45	27	83.5%
Quiz 10	34	10	67.9%
Quiz 11	36	3	76.2%

Notes: 1.) The entire class consisted of 46 students.
2.) Quiz Average determined by averaging individual student scores based on the number of students who participated in quiz.

Use of Clicker Quiz Results to Evaluate Effects on Small Group Discussion

Clicker quiz questions were qualitative in nature and primarily tested concepts discussed in assigned readings or material covered in previous lectures. Each question was presented using PowerPoint slides and students were allowed 30-seconds to read and answer the question via clicker. After 30-seconds, student responses for each multiple-choice answer (A, B, C, D, and E) were projected on the board, in the form of bar chart tabulations (refer to Figure 1), without

revealing the correct answer. If the class majority (usually above 60%) submitted the correct answer, the professor informed students that the majority gave the right answer and a student was randomly called upon to explain the basis for the correct answer, after which, the next quiz question was presented. When answers were broadly distributed across various multiple-choice answers (see Case 1 in Figure 1, correct answer A), or when responses were concentrated primarily on two multiple-choice answers (see Case 2 in Figure 1, correct answer A), students were given two additional minutes to small group discussion, prior to resubmitting answers. In cases where answers were still incorrect, even after small group discussion (i.e., after the second chance to submit answers to the same question), students were provided with a hint and allowed a third chance to reply to the question. Figure 2 provides a flow chart used to administer clicker quiz questions for initial and subsequent responses, once student difficulties were detected.



Case 1 Case 2

Figure 1 Representative Clicker Quiz Response Distributions, Prompting 2nd Chance

From an aggregate total of 158 clicker quiz questions, the class majority initially replied correctly to 129 questions (82%) and incorrectly to 29 questions (18%). Of the 29 questions initially answered incorrectly, second chance responses were allowed for students to reevaluate their answers through small group discussion. 20 questions (12%) initially answered incorrectly improved to a class majority correct, after allowing small group discussion in the second chance. This indicates that small group discussion was beneficial to student understanding and ability to reevaluate their answers. Nine questions (6%) initially answered incorrectly did not improve to class majority correct in subsequent second chance response, after small group discussion. Table 2 summarizes data used in analyzing these trends and evaluating corresponding results.

For the nine questions, initially answered incorrectly and not improved by a second chance small group discussion, additional data analysis and possible explanations are presented in Table 3. This table shows how percent correct responses changed, between correct and most popular answers, across first, second and third chances. Three questions (2%) improved to a class majority response correct in the third chance, after the professor provided a helpful hint. Six questions (4%) did not improve to a class majority correct in the second chance after small group discussion. Possible explanations for these instances are: 1.) Students were adversely influenced by answers displayed from first chance results, or 2.) Students who answered incorrectly in the first chance, overly influenced small group peers to the point of selecting an incorrect answer in the second chance. In the future to avoid students being influenced by first round answers, consideration should be given to not displaying any tabulated results until the second round.

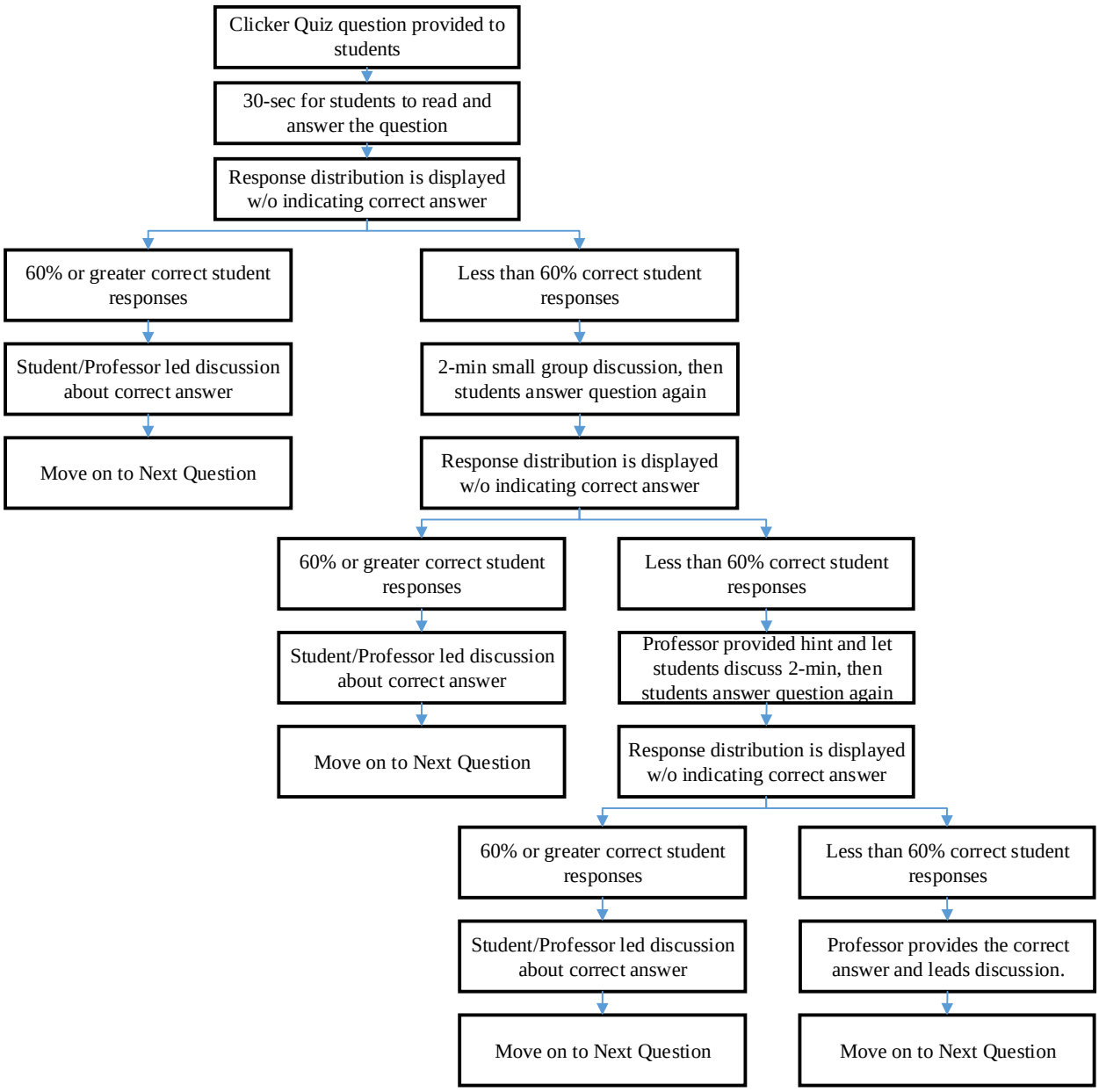


Figure 2 Flow chart used to administer clicker quiz questions for initial and subsequent responses

Table 2 Majority Class Response for 29 Questions that Allowed Small Group Discussion

Question	Correct Answer	Correct, 1st Chance	Correct, 2nd Chance	Correct, 3rd Chance
1	D	44%	85%	-
2	C	24%	51%	-
3	D	51%	82%	-
4	C	58%	95%	-
5	C	57%	96%	-
6*	C	18%	4%	-
7	A	43%	96%	-
8	A	21%	76%	-
9	D	26%	77%	-
10	A	62%	96%	-
11	D	54%	85%	-
12	D	48%	76%	-
13	D	45%	86%	-
14	A	39%	90%	-
15	A	45%	90%	-
16	B	58%	84%	-
17	A	58%	98%	-
18	E	58%	91%	-
19*	C	7%	2%	89%
20*	A	40%	34%	-
21	A	38%	59%	86%
22	D	45%	93%	-
23*	D	24%	31%	-
24*	B	27%	31%	-
25*	C	16%	36%	-
26*	C	27%	27%	72%
27*	D	25%	24%	-
28*	B	16%	21%	71%
29	E	33%	56%	-

Notes: * Nine (9) questions indicate majority class response incorrect after small group discussion

Table 3 Responses to 9 Quiz Questions Initially Answered Incorrectly by Class Majority

Questions Answered Incorrectly		Possible Answer	Response, 1st Chance	Response, 2nd Chance	Response, 3rd Chance
6	Correct Answer	C	18%	4%	-
	Most Popular Answer	A	49%	93%	-
19	Correct Answer	C	7%	2%	89%
	Most Popular Answer	D	55%	73%	0%
20	Correct Answer	A	40%	34%	-
	Most Popular Answer	B	42%	66%	-
23	Correct Answer	D	24%	31%	-
	Most Popular Answer	C	55%	64%	-
24	Correct Answer	B	27%	31%	-
	Most Popular Answer	C	41%	62%	-
25	Correct Answer	C	16%	36%	-
	Most Popular Answer	B	51%	44%	-
26	Correct Answer	C	27%	27%	72%
	Most Popular Answer	D	33%	53%	0%
27	Correct Answer	D	25%	24%	-
	Most Popular Answer	C	41%	76%	-
28	Correct Answer	B	16%	21%	71%
	Most Popular Answer	A	41%	71%	6%

Overall, from use of these eleven clicker quizzes it was observed that after discussion, students were able to correctly answer most questions. In cases where students were confused about a particular concept, the professor provided a more detailed explanation. Clicker quizzes were highly effective in encouraging students to participate in class.

Use of Clicker Quiz Results to Evaluate Student Performance on Final Course Grade

Clicker quizzes were voluntary, however, to further encourage student participation and ensure quizzes were taken seriously, a grade incentive was provided. More precisely, points were awarded each time a response was recorded, regardless of whether the answer was correct or incorrect, and additional points were earned whenever the answer was correct. As a result of these favorable course-grading policies, clicker quiz participation ranged from 63 to 100 percent, and average class participation across all eleven-clicker quizzes was 88 percent, which is deemed very high. However, so as not to overwhelm students with grading, clicker quizzes were strictly used as extra credit for the final course grade, as a result there were no penalties for not participating. This encouraged all students to participate and not only the ones who were aiming for high grade in the final class grade. At the end of the semester, each student's grade was averaged across all quizzes, and an extra grade percentage depending on performance (up to 5%) was applied towards students' final course grade.

Data recorded from clicker software was further evaluated to explore evidence of possible relationships between clicker quizzes grades and overall student performance on final course grade. In order to create a fair evaluation, an overall average quiz grade was adjusted to exclude any zero grades resulting from not participating in a quiz. A comparison of average quiz grade taken and overall final course grade did not produce any useful insights other than a general observation that average clicker quiz grade was typically lower than student performance for the final course grade. However, the number of clicker quizzes in which students participated is considered important in understanding if high participation in quizzes led to better overall performance in the class. Figure 3 provides a trend line projection for clicker quiz participation versus final course grade. Results indicate that students with the highest course grades participated in all or at least ten of eleven clicker quizzes. Student performance trends indicate that class participation and engagement were encouraged by clicker quizzes and helped students perform better in the course.

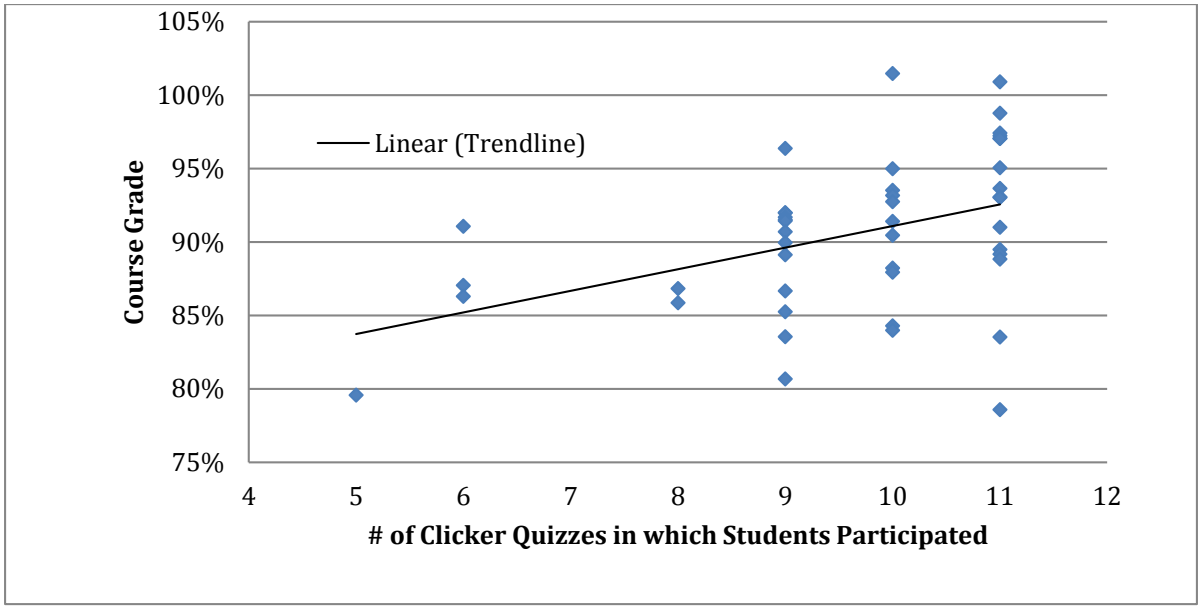


Figure 3 Trend Line Projection for Clicker Quiz Participation versus Final Course Grade

Student Feedback on Clicker Quizzes

At the end of the semester students were asked to evaluate the course and professor. Characteristic student feedback includes the following comments: 1.) "Clicker quizzes really allow us to review what we know and interact with the professor," 2.) "I liked that the professor spent time to make sure we knew all of the material with the clicker quizzes, and focus on concepts that we didn't understand," 3.) "The clicker quizzes were a fun way of reviewing material and helped me prepare for exams," and 4.) "The new methods tried in class made communication with students great and encouraged participation." It should be noted that no adverse comments regarding clicker quizzes were received. These representative student comments provide anecdotal evidence that active learning techniques are positively impacting the learning environment, and increasing student engagement in and out of classroom.

Use of Supportive Student Enrichment Activities

In addition to clicker quizzes as a primary active learning technique, supportive student enrichment activities were used to further enhance the learning environment. Structured enrichment activities included: "Students-teach-students", Jeopardy-style Competitions, Hands-on Field Experiences, Service Learning Projects, Community Service, Participation in Professional Organizations, and Interaction with Practicing Engineers, Public Officials, and Industry Representatives. Table 4 summarizes applications of student enrichment and active learning methods. Student performance data is not yet available for student enrichment techniques. Currently, student perception and feedback is being used to guide application. A brief description is provided for each of these activities.

Table 4 Summary of Active Learning and Student Enrichment Techniques

Instructional Focus	Activity	Class Size	Outcome Emphasis
Active Learning	Clicker Quizzes	46	Problem Solving
Student Enrichment	Student-Teach-Students	16/18	Communication
	Jeopardy Competitions	74/47	Contemporary Issues
	Field Experiences	various	Engineering Design
	Service Projects	various	Public Policy
	Professional Organizations	various	Ethical Responsibility
	Engineer Interactions	various	Lifelong Learning

"Students-Teach-Students," These lectures place responsibility on students to teach new course material to their peers. Students are assigned a course topic, which necessitates considerable preparation and understanding in order to teach their peers. Student presenters are encouraged to provide handouts, notes, and/or PowerPoint presentations, plus use approaches to keep their classmates engaged. The professor is on-hand to assist students through lecture material, if necessary. Engineering management students were assigned to teach various aspects on communication skills and engineering ethics. The class size was small (maximum of 16) so all students were required to participate. Material covered by students did not involve excessively challenging concepts or technical procedures. Afterwards, students were required to complete lecture evaluation forms. A total of 34 students submitted evaluation forms and noticeably none of the students disliked the "Students-Teach-Students" lectures. Student feedback included: "These lectures kept us engaged, however, should not be used every week," "I was impressed with how comfortable students were with presenting." "This type of class is very effective because it teaches us to fully understand a topic to a high degree needed to teach others," "This class was beneficial for our public speaking skills." "It's different and insures students are reading the textbook." Based on overall feedback, it was evident students enjoyed and benefited from these lectures, and found this instructional approach engaging.

Jeopardy Competitions, Jeopardy competitions were used to stimulate student interest in course concepts and subject matter. Participants were presented with facts in the form of an answer, and must respond in the form of a correct question. Jeopardy questions were used to review for exams in Transportation Engineering with class sizes of 74 and 47 students. Questions typically covered five primary categories and included various point awards based on the degree of difficulty. Students were divided into two teams that competed against each other. The first person from a team to raise their hand was allowed to answer a question. The team earning with the most points was declared the winner. If no one knew the answer, students had an opportunity to discuss with their team members. This promoted highly engaged class discussions. If a team was unable to answer correctly, the competing team had an opportunity to answer. There was no time limit, as some answers were longer and more difficult. Student response to Jeopardy competitions was extremely positive, to the point that students asked to replace all regular review sessions with Jeopardy game sessions. As a result, material covered via Jeopardy questions was answered correctly on the exam by an overwhelming majority of students. Even though Jeopardy has apparent benefits, is not practical for use throughout the semester, as it requires considerable preparation time, and frequently consumes an entire 50-minute class session.

Hands-on Field Experiences, Providing field experiences to put into practice material learned during class, constitutes a vital enrichment to students' learning experience. Incorporating hands-on field experiences was used a helpful means to foster deeper student understanding. Hands-on activities are informed through material covered in class and the scope of field exercises are much more limited in scope when compared to community service projects. Transportation engineering students were asked to collect speed and volume data at designated roadway sections for a one-hour period of time. Students maintained a cumulative vehicle count for assigned locations and recorded vehicle speeds using radar speed guns. Based on collected data, students calculated various traffic stream parameters such as time mean speed, space mean speed, hourly flow rate, traffic density, probability of arriving vehicles, and probability of headway between successive vehicles during a specified time period.

Service Learning Projects, Research Projects, and Community Service, Service and research projects are commonly performed on behalf of local government or non-profit organizations within the local community. Projects provide students with opportunities to apply knowledge, learn new concepts, work in teams, understand the needs of the profession, and potentially develop new ideas that can contribute to improvement of the global society. Through participating, students gain first-hand knowledge of engineering practice, actively contribute to their community through the service they perform, and develop a personal appreciation for civic responsibility all of which are very beneficial personal and professional growth of students. Projects are supported by a faculty advisor, linked with classroom instruction, and conducted on a voluntary basis. Service projects have included traffic studies for town administrators, parking lot and circulation design for a local community, and pedestrian/bicycle facility planning. Specific student research opportunities have included roundabout traffic operation, pavement markings, work zone safety, high occupancy toll lanes, vehicle occupancy estimates, among many others. A limitation of this approach is that only a portion of students, maybe 25 percent, takes advantage of this type of rich and challenging learning experience.

Participation in Professional Organizations, Meetings and Forums, Providing opportunities for students to develop their knowledge and skills though participation in professional organizations, technical meetings, and interactive forums serves as a valuable means to engage students with professional role models, help students develop networking skills, connect students with possible career paths and convey how engineers serve society. Students participate in a range of professional organizations including American Society of Civil Engineers (ASCE), Society of Women Engineers (SWE), Institute of Transportation Engineers (ITE), Society of American Military Engineers (SAME) and others. These types of professional activities can help students explore career directions and identify potential employment opportunities. It is estimated that 50 percent of undergraduate civil engineering students at our institution participate in this type of learning experience.

Interaction with Practicing Engineers, Public Officials, and Industry Representatives, Many educators and practicing engineers suggest that students cannot learn everything they need to know to become an effective practicing engineer through classroom instruction only. Interacting with the public officials and local decision makers occurs in a highly dynamic environment that is difficult to replicate in the classroom. In order to further student knowledge and understanding of these crucially important engineering proficiencies, extracurricular educational activities commonly include; interaction with public officials; participation in design charrettes and public involvement; attendance of transportation planning forums; attendance of transportation study presentations; and site trips to visit vendors and contractors.

Summary and Conclusions

Numerous beneficial educational outcomes are being achieved through application of active learning techniques in classroom instruction[20, 21, 22]. Active learning provides enriching academic learning opportunities that are not as readily accomplished within a traditional classroom setting solely based on direct instruction methods. Data analysis from using clicker quizzes in the classroom showed that clicker quizzes were able to increase student participation and engagement during class time. Additional results from student performance on clicker quizzes include the following:

- Average clicker quiz performance of 81% resulted over the semester from 46 students taking 11 clicker quizzes, including a total of 158 questions.
- 129 (82%) of the 158-clicker quiz questions were answered correctly by a majority of students on the first attempt.
- Of the 29-clicker quiz questions initially answered incorrectly by a majority of students, subsequent small group discussion led to an improvement of 20 (70%) questions being answered correctly by a majority of the students.

Overall, engaging assignments, energetic class activities, and structured enrichment experiences provide students intrinsic motivation to strive for excellence in developing their technical skills and applying their knowledge. Ideals of student responsibility to rigorously prepare for professional practice are being positively influenced and inspired through more engaged participation in meaningful student learning activities that challenge students to apply their knowledge to understand and help address real-world engineering problems. These observations

are supported from implementation, analysis and evaluation of active learning techniques and enrichment activities described in this paper.

Future Steps

Student performance and feedback confirm active learning methods and activities are positively impacting academic instruction and student learning environments in engineering. Obviously a number of improvements are needed for further implementation of these methods and student development model to provide the level of results envisioned for graduating engineers. An important future step is development of more robust assessment methods to obtain performance data from the various student enrichment activities described in this paper, beyond current results focusing merely on clicker quiz data. A larger, universally focused improvement will be institutionalizing the documentation process to more broadly capture and encompass student development activities, longitudinal data trends, and related assessment evidence through expanded functionality of web-based software. This type large-scale advancement would constitute an important step towards further instructional advancement by establishing a comprehensive data-driven approach to achieve student development outcomes needed to prepare graduates to meet the escalating challenges of professional practice.

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