Assessment and comparison of online and traditional delivery for analyzing environmental impacts and sustainable engineering

Bradley Striebig and Steven Harper
Department of Engineering, James Madison University

Abstract

Engineering was introduced for the first time at James Madison University (JMU) for students entering college in the Fall of 2008. The mission of the new program stated "James Madison University's engineering graduates will improve the sustainability of our world by participating in projects in which they analyze problems and design solutions in the context of technical, economic, environmental and social impacts." Online versions of the ENGR 411: Fundamentals of Sustainable Engineering and Design course were offered during the summer 2014 10-week session to allow more students to take the course, and allow students scheduling flexibility. This paper presents and compares learning objects for traditional course delivery in the classroom to two pilot-program online course offerings during a 10-week summer.

The percentage of students answering questions correctly on a final assessment examination was similar for the traditional semester-based course and the online course, with a few exception. Traditional and on-line classes scored within 10% of one another for most qualitative questions, with the most significant exception of a single question from the final summary chapter of the course in which online students performed better. Traditional and online students scored similarly for most quantitative problems, with online students preforming slightly better on water quality related topics, and traditional classes scoring slightly better in air quality and climate change topics.

Overall the assessment scores for both cohorts of students were nearly identical. Students noted trade-offs in learning styles between the two types of courses, and for this reason did not favor one method over another, but valued the opportunity to have both traditional and online options available. The assessment yielded results that have the potential to improve the online course by identifying a need for some synchronous "live" class meetings. In addition, the traditional in class course may be improved through the development of a more specific course plan, fine-tuning of the assessment instrument, and the development of supplemental on-demand lectures.

Keywords

Sustainability, online learning, sustainable development, engineering applications

Background

Sustainability is important in manufacturing, construction, planning and design. Alleby *et. al*. state that: "Sustainable engineering is a conceptual and practical challenge to all engineering disciplines.[1]" Environmental engineering and chemical engineering textbooks may cover some basics concepts of sustainability, but the extend and breadth of knowledge is insufficient to meet the multifaceted demand associated with engineering sustainable processes and products.[2]

Crittenden suggests that sustainable solutions include the following important elements/steps: (a) translating and understanding societal needs into engineering solutions such as infrastructures, products, practices, and processes; (b) explaining to society the long-term consequences of these engineering solutions; and (c) educating the next generation of scientists and engineers to acquire both the depth and breadth of skills necessary to address the important physical and behavioral science elements of environmental problems and to develop and use integrative analysis methods to identify and design sustainable products and systems.[3]

The inaugural freshman engineering class at JMU was accepted in August 2008. The new engineering program offers a single, interdisciplinary engineering bachelor's degree that is designed to meet ABET accreditation standards and prepare graduates for the FE examination. In addition to the ABET and FE standards, the engineering program was created to emphasize and develop engineering graduates that understand and can utilize the concepts of sustainability in conjunction with standard engineering analysis and design curriculum components. The engineering program has developed a two-course sequence of sustainability-focused courses focused on the engineering applications of sustainability science, environmental impact analysis, and applications of models of sustainability, such as Green Building analysis and Life Cycle Analysis (LCA). The two-course sequence was developed to address the mission statement of the department:

Department of Engineering graduates will improve the sustainability of our world by analyzing problems and designing solutions in the context of technical, economic, environmental, and social impacts.

The first course "ENGR 411: Fundamentals of Sustainable Engineering and Design" is focused on introducing general sustainability concepts and quantifying environmental impacts. The second course, "ENGR 412: Sustainable Engineering & Design II" focused on material and energy balances and life cycle assessment. The two-course sustainability sequence includes foundational knowledge of environmental impact assessment methods, life cycle analysis, and energy considerations.[4] Prerequisites for such a course are the foundational math courses in calculus, chemistry, and physics. The sustainability sequence was designed for sophomore to senior students in engineering and is applicable to all engineering disciplines.

The sustainability-focused curriculum introduces a new approach to sustainability that includes foundational knowledge of environmental impact assessment methods, life cycle analysis, and energy considerations that are being adopted in many accredited engineering and technology programs. The sustainability-focused curriculum is focused upon applying engineering principles to real-world design and problem analysis. It includes specific step-by-step examples and case studies for solving complex problems that appear throughout the two courses. Both courses involve conceptual and applied problems at various levels of difficulty. Both courses also apply the principles of sustainable design to issues in both low-income and high-income countries.

The interest in the program and the sustainability course entitled "Fundamentals of Sustainable Engineering and Design" has grown from an initial course size of 10 students in 2010 to over 86 students taking the course in 2014. Online versions of the course were offered during the summer 2014 10-week session to allow more students to take the course, and allow students scheduling flexibility. This paper presents and compares learning objects for traditional course delivery in the classroom to online course offerings during a 10-week summer semester.

The summer session courses were divided into two sections, one was offered as part of an in-depth sustainability field study abroad program conducted in Benin, West Africa, which included a separate 3-week field study course on sustainable development. The second section was an online only course. Both sections ran concurrently.

The assessment instrument used for the traditional in class courses and the summer session courses were nearly identical in the questions and answers, however some small concessions were made for the online deliver system, Canvas, which was used for the assessment of the online course.

The expected course outcomes and related ABET criteria associated with the Fundamentals of Sustainable Engineering and Design are shown in Table 1.

Table 1. Expected outcomes and related ABET criteria for sustainability-focused courses

ID	**Course Objectives** Upon successful completion of this course, the student will be able to:	**ABET Outcomes**
1	Perform calculations involving conventional units utilized in engineering	a, e
2	Solve basic equilibrium problems in environmental chemistry related to pH and solubility	a, c, e
3	Prepare mass balance equations to determine the impacts of pollutants upon the environment	c, e
4	Solve mass balance problems related to determine the impacts of pollutants upon the environment	a, c, e
5	Calculate and describe the impact of anthropogenic emissions on the oxygen content in natural aqueous environments	a, c, e
6	Describe the impact of anthropogenic sources on water and air quality	a, c, f, h, j, k
7	Describe the relationship between community sustainability, global climate change, environmental impacts, economic projects, and fossil fuel emissions	f, h, i, j
8	Develop frameworks for conceptualizing complex, open system problems, and the inter-relationship of environmental, energy, economic, health, technological, and cultural factors	c, f, h, i, j

The course was designed to teach these study skills through an approach that relied heavily upon the assigned textbook, and advanced copy of Engineering Applications in Sustainable Design And Development, which was written specifically for the sustainability curriculum.[5] The textbook closely aligns with course outcomes allowed for more self-directed learning, through assigned reading, completion of a workbook (or handwritten notes based upon the assigned reading and example problems) and completion of assigned homework problems that closely align with examples in the textbook. The Topics covered in the course align closely with the textbook as shown in Table 2. Study skills required for successful completion of the course were made explicit and taught during class meeting times. Class meeting times focused primarily upon interactive question and answer sessions, assessments based upon expected course outcomes, and finally supplementing and contextualizing the subject matter.

Table 2. Course Topics in Fundamentals of Sustainable Engineering and Design

Topic ID	Textbook Chapter	Description
1	1	Sustainability, Engineering, and Design
2	2	Analyzing Sustainability Using Engineering Science
3	3	Biogeochemical Cycles
4	4	Water Quality Impacts
5	5	Impacts on Air Quality
6	6	The Carbon Cycle and Energy Balances
7	7	Models for Sustainable Engineering

The overarching goals of the sustainability sequence of courses was to provide students not only with a working definition of what sustainability and engineering may mean in context to one another, but also to provide engineering tools to be able to evaluate and predict the impacts of various design choices upon sustainability indicators.

Assessment instruments were developed over time to determine the level of success of meeting the course objectives. Opportunities also presented themselves to offer an online version of the course to allow students to complete the course while studying abroad or simply to allow greater flexibility in their scheduling.

The principle author has taught distance education courses since the 1990s. Some objectives and content appears to lend itself more easily to distance or online learning than other content. The authors wanted to understand the differences in outcomes for the sustainability related objectives between the traditional semester based approach and an online version of the course.

The final exam for the course was used as an assessment tool. Thirty-eight topical question groups, shown in in Table 3, were used to evaluate the performance related to specific topics and the objectives listed in Table 1. The questions were asked of up to 34 participants during the 2013/2014 academic year and up to 21 participants in the online course. Twenty-one of the questions were qualitative in nature and seventeen questions involved quantitative calculations.

Table 3: Assessment topics, related objectives and data from the traditional in class course and online course.

Question ID	Problem	Topic	Objective	In class			Online		
				# Correct	#	%	# Correct	#	%
Conceptual Problems									
1	UN MDGs	1	8	18	21	86%	9	9	100%
2	HDI	1	8				8	11	73%
3	Sustainability Definition	1	8	34	37	92%	10	10	100%
4	IPAT	1	8	7	8	88%	5	9	56%
5	Geologic Reservoirs	3	8	12	13	92%	11	11	100%
6	Water reserves	3	8	16	23	70%	7	10	70%
7	Water Budget	3	8	7	8	88%	6	8	75%
8	Pathogens in water	4	7	15	21	71%	10	11	91%
9	Water related mortality	4	7	21	24	88%	10	10	100%
10	BOD	4	7				6	9	67%
11	Stratification	4	7	18	37	49%	6	8	75%
12	Nutrification	4	7	31	37	84%	8	9	89%
13	AQI	5	7	42	45	93%	8	8	100%
14	PM Health Effects	5	7	31	45	69%	11	13	85%
15	NAAQS	5	7	8	8	100%	8	8	100%
16	Greenhouse Gas Temp	6	7	11	14	79%	2	4	50%
17	CO_2 residence time	6	7	18	24	75%	7	8	88%
18	CO_2 History	6	7	9	13	69%	4	9	44%
19	CO_2 Increase	6	7	7	13	54%	6	13	46%
20	Biocapacity	7	8	1	8	13%	7	14	50%
21	Ethics	1	8				10	11	91%
Analytical Problems									
22	HDI	1	8	40	45	89%	20	21	95%
23	Exponential change	1	7	17	24	71%	12	21	57%
35	Units	2	1	30	45	67%	16	21	76%
22	Unit conversion	2	1	25	45	56%	17	21	81%
37	Chemical Balance	2	2	22	45	49%	10	21	48%
25	Strong Acid	2	2	7	24	29%	4	8	50%
26	Weak Acid equilibria	2	2	28	45	62%	2	8	25%
24	Mass Balance	3	3	41	45	91%	16	21	76%
36	Mass	3	3	29	34	85%	6	21	29%

	Balance								
27	Water budget	3	4	30	45	67%	21	21	100%
28	Water budget	3	4	27	45	60%	18	21	86%
29	BOD_5	4	5	38	45	84%	16	21	76%
30	Streeter-Phelps Model	4	6	11	45	24%	18	21	86%
31	Streeter-Phelps Model	4	6	11	45	24%	5	21	24%
32	AP-42 Emission Factor	5	5	34	45	76%	12	21	57%
33	Stability	5	6	13	21	62%	17	21	81%

Results and Discussion

The sample sizes for the online course was limited to 21 participants. Not all participants answered identical exam questions, the same number of questions were answered for each topic. Due to the limitations of the data set available, the assessment data was collected and the investigators looked for large differences (> 10%) between the traditional in class course outcomes and the online course outcomes. No statistically significant difference occurred between overall scores on the assessment instruments. The averages of scores on the assessment for two traditional course offerings were 72% and 70%. Scores on the assessment for the study abroad online component of the class were 72% and the average score for the online only course was 71%.

The data was further evaluated based upon qualitative (Figure 1) and quantitative (Figure 2) topic questions to improve the instructor's understanding of what topics or objectives benefit from in-class lectures and which if any benefit form online supporting materials. The qualitative and quantitative data was used collectively to evaluate the course objectives (Figure 3).

Six topics were assessed using *qualitative* questions, only topic number 2 that covers engineering sciences was not evaluated using qualitative questions. The percentage of question answered correctly between the traditional in class and online courses differed by more than 10% only for Topics 6 (The Carbon Cycle and Energy Balances) and 7 (Models for Sustainable Engineering). The difference in the assessment scores for Chapter 6 is marginal, however, Chapter 6 during the traditional semester is covered during the last week of class, when semester project reports and some finals may impact time spent on task for this particular course. Topic 7 is used as a summary chapter and transition chapter between the first (ENGR 411) and second (ENGR 412) sustainability course. It typically only receives 1 hour of class coverage time during the traditional in class, with instructions to the students to read the material and requires the largest amount of self-directed study of any of the topics covered during the traditional in class course. Unlike topics 1- 6 there were no online lectures available for topic number 7 and students online had to rely entirely on self-directed learning from the textbook. The assessment results shown here would indicate that the online students have mastered the techniques associated with online learning, to a significantly greater degree (67% improvement) than students that have taken the class through a traditional lecture based approach. The assessment and teaching techniques were not designed explicitly to test this characteristic and the results were surprising when the data was evaluated. However, the results seem to indicate that the practice of self-directed learning required for completion of the online course lead to better results when self-directed learning was required. It also possible that students in the traditional in class course deal with complex time and schedule issues at the end of a semester and self-directed learning of this material was not a priority. The investigators plan to further evaluate the influence and relationships for the ability of online learning to improve self-directed study habits.

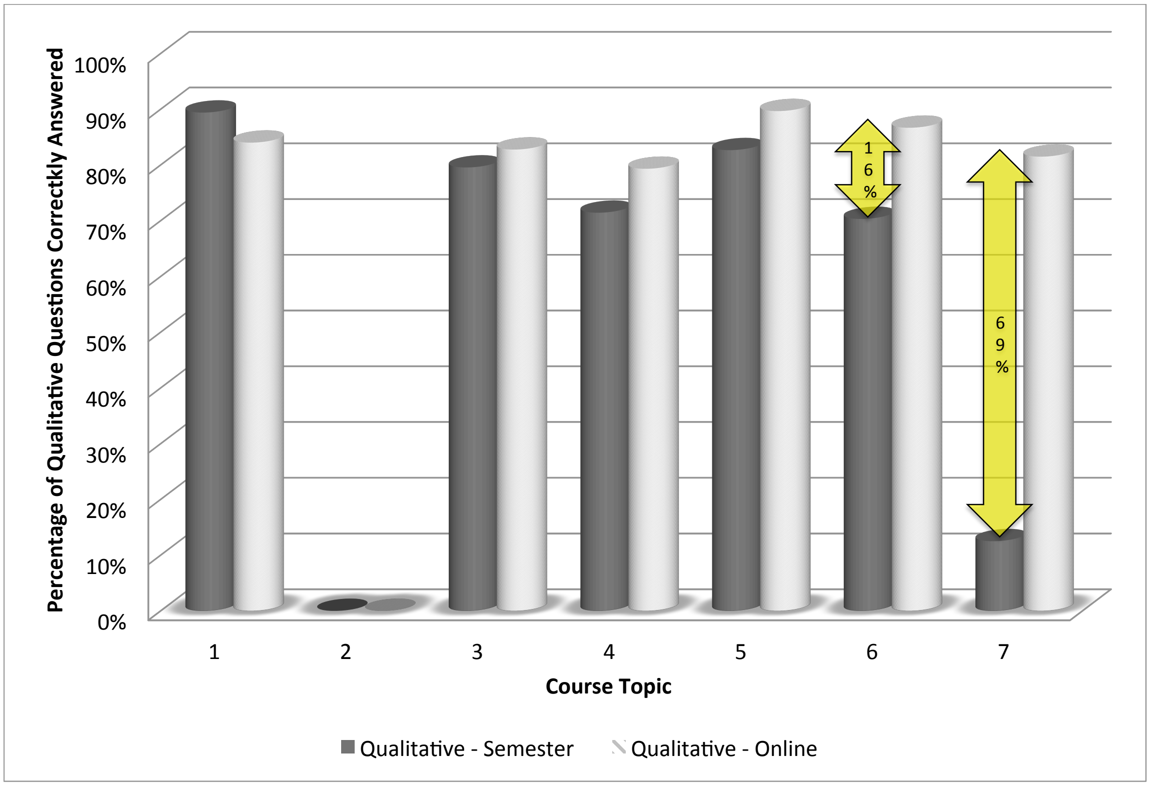

Figure 1: Comparison of qualitative question responses between the traditional in class and online sustainability course

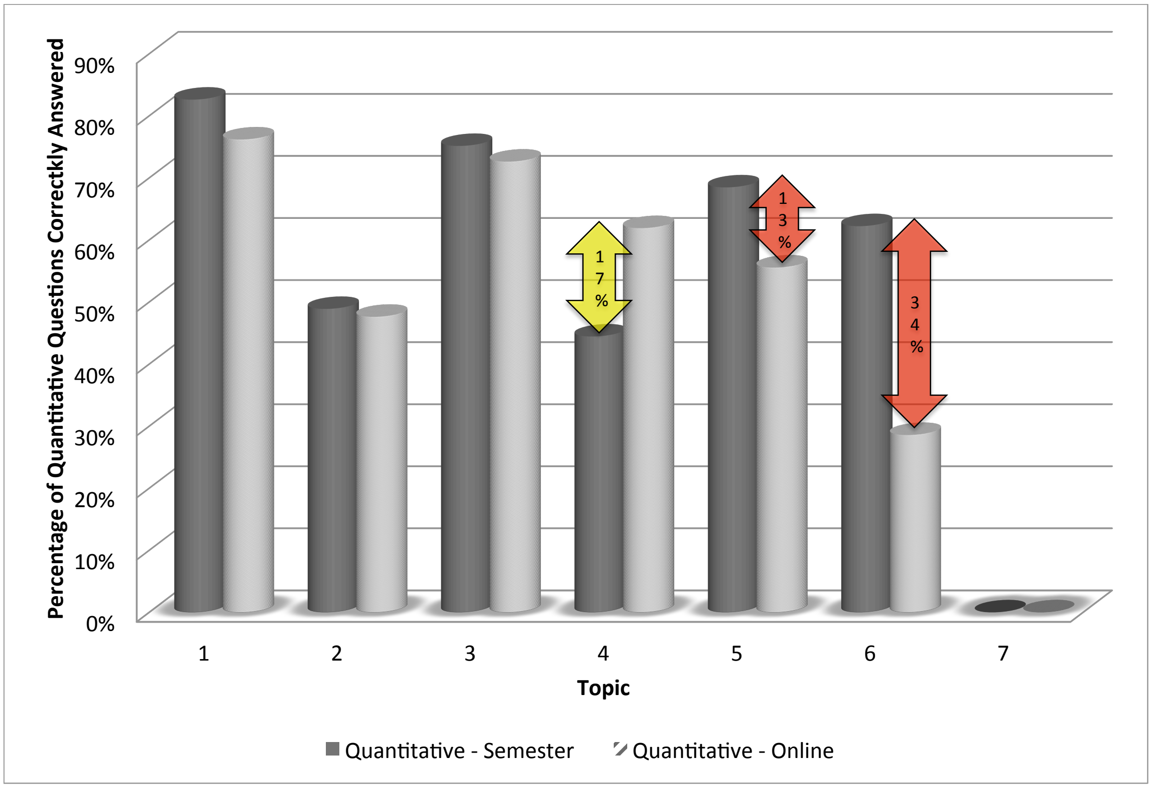

Figure 2: Comparison of quantitative problem-solving responses between the traditional in class and online sustainability course

Six topics were assessed using *quantitative* problem-solving responses, only topic number 7, that covers Models for Sustainable Engineering was not evaluated using quantitative questions for the reasons previously discussed. Generally there was little difference among traditional in class and online participants for the problem-based questions. The traditional in class students performed better in four of the six topic areas. Generally the problems become more complex with the higher topic numbers. It has been the experience of the instructor that the traditional classroom setting works well for providing examples and feedback during class time for problem-based questions. The data seems to support this observation, especially where there are complex interactions such as in air quality dispersion (Topic 5) and climate change modeling (Topic 6). Online students did perform slightly better (by 17%) than students in the traditional classroom in two areas, most especially in water quality analysis (topic 4). There is no obvious reason for this difference based upon course content, however topic 4 typically occurs during the mid-term exam portion of the semester. It also possible that students in the traditional in class course deal with complex time and schedule issues during this time period, as has been reported anecdotally by students. The online students may benefit from focusing on only one subject and scheduling flexibility. The investigators plan to further evaluate the influence of scheduling and time management issues for particular topics for traditional in class students. The instructors may also research more interactive approaches for complex problem solving portions of the online offering of the course, particularly in Chapter 6.

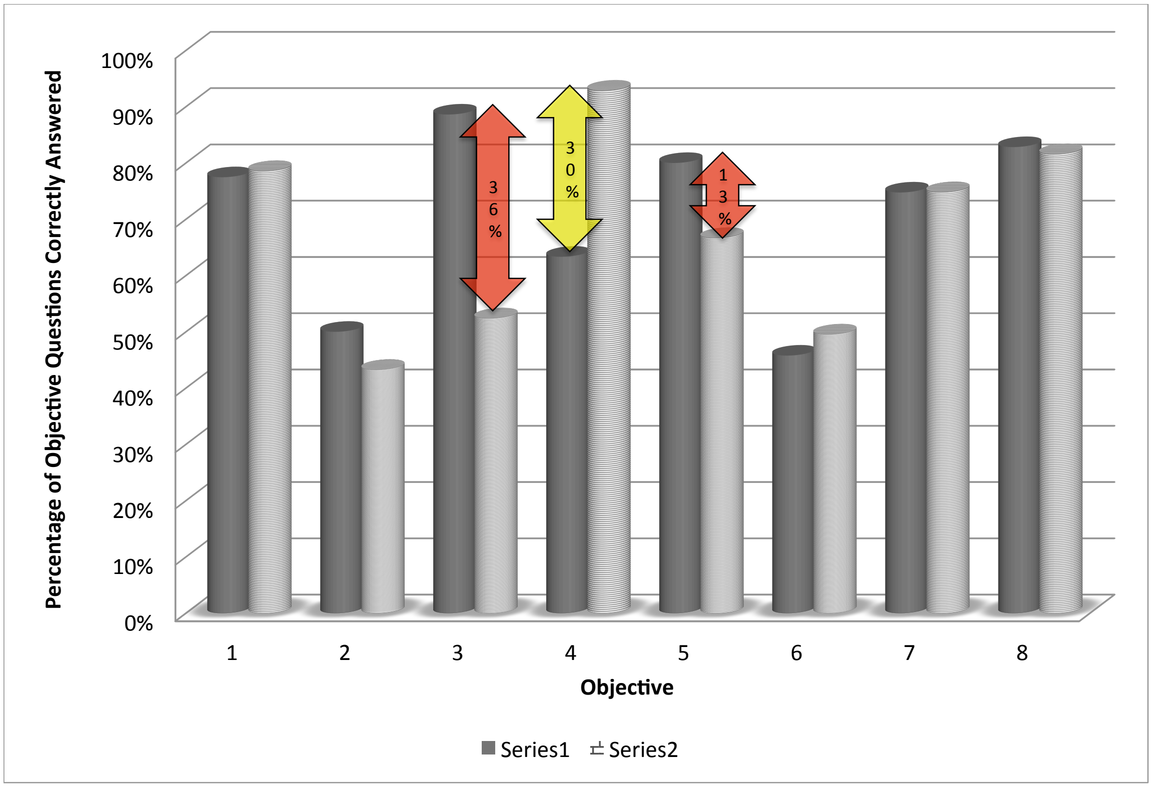

Figure 3: Comparison of performance in meeting sustainability course objectives between the traditional in class and online sustainability course

The analysis of course objectives and the comparison between the traditional in class and online course approach provides a more detailed breakdown of how course delivery may impact specific class outcomes. Recall, that overall, the assessment scores between the traditional in class and online course were nearly identical. However, subtle differences become apparent when evaluating the individual class objectives.

There was less than 10% difference between the traditional in class and online course outcomes for objectives 1, 2, 6, 7 and 8. Objectives 1, 7 and 8 are primarily qualitative outcomes and both student groups did very well in meeting the qualitative outcomes. Objective 2 (solve basic equilibrium problems in environmental chemistry related to pH and solubility) relates to long-term difficulties students have exhibited applying fundamental chemistry concepts to environmental impacts analysis. These difficulties have been described previously[4], but both traditional in class and online course participants performed poorly on this final assessment. Objective 6 (describe the impact of anthropogenic sources on water and air quality) was based primarily on the quantitative complex environmental models that correspond to topics 4, 5 and 6, discussed above. Students have difficulty meeting this course objective, possibly due in part to the complexity of the models that utilize chemistry principles for determining environmental impacts.

Objectives 3 and 4 are related to one another. Objective 3 focused on the ability of students to prepare mass balance equations to determine the impacts of pollutants upon the environment. Objective 4 focused the ability of students to solve mass balance problems related to determine the impacts of pollutants upon the environment. It has been the instructor's experience that student's in class generally benefit from examples and practice defining system constraints and setting up mass balance problems, which is consistent with the data collected for Objective 3, that show students in a traditional classroom scoring 36% better than the online cohort. The 30% higher scores for the online class in meeting Objective 4, may indicate that the online students in these cohorts exhibited a higher ability to solve problems, if they can correctly understand the algebraic relationships between the problem statement and solution. In the online course, all work was asynchronous. The observation herein indicate that the online students may benefit from specifically designed synchronized "live" sessions designed to reinforce methods to relate the context of a problem to the algebraic equation required to solve the problem.

Objective 5 (calculate and describe the impact of anthropogenic emissions on the oxygen content in natural aqueous environments) is based on complex mathematical models and problem solving ability. Again, the traditional in class cohort of students performed slightly better (by 13%) than the online cohort. This observation indicates, again, that the online students may benefit from specifically designed synchronized "live" sessions designed to solve complex problems

The study is on-going with additional interesting results expected for the Fall 2014 offering of the course (42 participants) and the Spring semester of 2015. The Fall 2014 course offering benefits from a very detailed syllabus that was created for the online course and adapted to the Fall offering. The online lecture materials that were developed are also available as tutorials for the Fall offering of the course, but were unavailable for previous offerings of the course.

The next offering of the online course will utilize a few "live" synchronized lectures to provide additional resources to help students contextualize and solve complex problems.

Summary

In summary, the instructor was pleased with the outcomes demonstrated by the online course option. The primary purpose of collecting the assessment data was to ensure that there was no significant overall achievement gap between the traditional in class course offering and online course offering. Overall the assessment scores for both cohorts of students were quite similar. There were some difference in observed assessment data for performance on specific topics and the ability to meet specific objectives. Students noted trade-offs in learning styles between the two types of courses, and for this reason did not favor one method over another, but valued the opportunity to have both traditional and online options available. The assessment yielded results that have the potential to improve the online course by identifying a need for some synchronous "live" class meetings. In addition, the traditional in class course may be improved through the development of a more specific course plan, fine-tuning of the assessment instrument, and the development of supplemental on-demand lectures.

References

1 Allenby, B. *et al*. Teaching Sustainable Engineering. 2007. Journal of Industrial Ecology. 11(1)8-10.

2. Azapagic, A. et al. How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum. European Journal of Engineering Education. 2005. 30(1)1-19.

3. Crittenden, J.C. J. Clean Technol. Environ. Policy 2002, 4(1)6-7.

4. Striebig, B., Ogundipe, A., and Morton, S. 2014. Lessons in implementing sustainability courses into the engineering curriculum. 121st ASEE Annual Conference & Exposition, June 15-18th, 2014, Indianapolis, IN.

5. Striebig, B., A. Ogundipe and M. Papadakis. 2016. Engineering Applications in Sustainable Design and Development: 1st Edition. Cengage Publishing. Boston, MA. 746p.

Bradley A. Striebig, Ph.D.
Professor of Engineering
James Madison University

Dr. Striebig is a founding engineering faculty member at James Madison University. Dr. Striebig came to the JMU School of from Gonzaga University where he developed the WATER program in Benin in cooperation with Dr. Susan Norwood. Dr. Striebig is also the former Head of the Environmental Technology Group at Penn State's Applied Research Laboratory. Dr. Striebig is the lead author of *Engineering Application in Sustainable Design and Development*, a new textbook that will be published by Cengage Publishing in 2015. His engineering and professional photography work has been published in numerous books, journals and magazines.

Steven Harper, Ph.D.
Associate Professor of Engineering
James Madison University

Steven Harper is an Associate Professor of Engineering in the College of Integrated Science and Engineering at James Madison University. Harper earned a PhD in Systems and Entrepreneurial Engineering and an MS in Business Administration from the University of Illinois at Urbana-Champaign. He also holds an ME in Electrical Engineering from the University of Virginia and a BS in Engineering Physics from the University of California, Berkeley. His research interests include the effects of diversity, multiple intelligence and decision-making processes on small group performance. His research has been published in journals including the *Journal of Business Research*, *Team Performance Management*, *Engineering Economist*, and *ASME Journal of Mechanical Design*. Previously, Harper was an Officer in the US Navy where he served on three submarines and held several program management positions.