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Implementation of a Project-based Learning Approach to Undergraduate Education: Case Study of Optimization Course in Industrial Engineering

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Abstract

This paper focuses on the benefits of a course-based undergraduate research project experience in industrial engineering. Undergraduate students in optimization course are involved in a research project on recognition of recycling opportunities in a health care system located in Ohio, U.S. A new multi-criteria decision-making technique based on a fuzzy set theory and VIKOR method is applied to assess health care waste disposal technologies including incineration, steam sterilization, microwave, and landfilling. The proposed approach estimates the GHG reductions and potential economic benefit derived from increased recycling for the case study. The key findings from the study demonstrate that the undergraduate research improves the students' attitudes towards engineering, higher-order cognitive learning, self-efficacy, ease of learning the subject matter, team working and communication skills; all relevant objectives related to engineering accreditation.

Keywords: Course-based undergraduate research project, Learning Assessment, Optimization, Health Care system, Industrial Engineering, Multi-Criteria Decision Making

Introduction

Undergraduate students' involvement in research projects are attracting more attention in the last decade (Shaffer et al., 2010; Harrison et al., 2011; Rowland et al., 2012; Jordan et al., 2014). Literature review indicates that undergraduate research projects offer several advantages over traditional courses by enhancing self-efficacy and preparing a unique opportunity for students to put their knowledge into practice (Shaffer et al., 2014). Such experience allows students and instructors to collaboratively bridge the research and classroom and provide research experiences for students relative to traditional individual mentored research. Undergraduates who are involved in research report cognitive gains such as a) learning to think and analyze, b) affective gains such as delight, c) psychosocial gains such as belonging to a team, identifying as an effective engineer, and d) behavioral gains such as motivations to pursue graduate education or careers in engineering (Laursen et al., 2010; Lopatto and Tobias, 2010).

Studies of undergraduate research experiences have been criticized for some reasons such as counting on students to convey their own knowledge and skill gains, applying techniques that lack validity and reliability, challenging and allotting more time and effort by instructor (Brownell et al., 2013; Linn et al., 2015). Nonetheless, a rising number of well-designed and properly controlled studies are indicating that such an approach can influence a students' learning, development, and educational and career path (Eagan et al., 2013; Hurtado et al., 2008; Schultz et al., 2011).

This paper analyzes the students' attitude and performance after experiencing a real research project in optimization course. Upon completion of the course, students showed increased confidence performing optimization techniques and reported positively on doing a research project in class.

Course Overview and Research Methodology

In this research, the course of Optimization for Industrial Engineering (IET 36200 undergraduate level, 3 credit course) was assessed at Purdue University-Fort Wayne. The course description for the IET 36200 Optimization for Industrial Engineering course is: "This course covers operations research (linear programming, integer programming, transportation problems, etc.) methods applied to optimization in a manufacturing environment."

This study was conducted across two semesters (each semester had 16 weeks, class size of 20 students) for the same course: in the fall of 2016 for a lecture-based classroom course and in the fall 2017 for a mix of lecture-based and problem-based classroom course. The grade distribution in fall 2016 and 2017 was as follows:

HW and Group assignment 25%, Midterm Exam 25 %, Final Exam 30%, Group Project (presentation and technical report) 20%. Assessment of project report and oral presentation were conducted using proper rubrics (see Appendix A and Appendix B).

In fall 2016, faculty asked students to apply one of optimization techniques on a numerical example as a course project while in the fall 2017 the faculty decided to engage students in a real research project to apply a multi-criteria decision-making technique and optimize solid wastes for a health care system. In fall 2017, students and instructor had five onsite visits from a health care system to tackle their problem. Every other week, student teams had a group meeting with their instructor and reported their progress in achieving objectives.

As the project defined in Fall 2017 were intended to address a real problem in a health care system, the course modifications involved a two-week training module for the students to specifically familiarize them with application of optimization and decision-making techniques in health care systems. The research project provided an opportunity for the students to work in interdisciplinary teams, enhance professionalism, and knowledge of contemporary issues – creating 'well rounded' and 'job market ready' engineers upon graduation. The health care domain led to increased student motivation and enhanced learning of optimization techniques. The research project somehow improved students' understanding of multi-criteria decision making over some other approach.

Summary of Conducted Research Project in Optimization Course

Firstly, the two objectives of the research project were clearly defined: a) evaluate recycling opportunities in a health care system and b) apply a new multi-criteria decision-making technique based on intuitionistic fuzzy set theory and VIKOR method to assess health care waste disposal technologies. Then, the students were teamed up and did a broad literature review on health care waste. They found that health care wastes and health stream have steeply increased in recent decades due to increased population, number, and size of health care facilities, as well as the use of disposable medical products (Manga et al., 2011; Moreira et al., 2013; Dursun et al., 2011a; Dursun et al., 2011b; Liu et al., 2013; Abed-Elmdoust and Kerachian, 2012). They categorized waste in health care systems as follows.

Table 1. Major healthcare waste streams

Health care waste category	Examples
a) General wastes	Wastes derived from normal inpatient wards, outpatient examination rooms, first aid areas, administration, cleaning services, kitchens, stores, and workshops.
b) Infectious wastes	Potentially infectious wastes that require special management inside and outside the health care system such as microbiological laboratory wastes (blood and blood containers, Serologic wastes, etc.), discarded surgery wastes, and air filters that contain bacteria and viruses.
c) Pathological wastes	Tissues, organs, and fluids removed during surgery or autopsy medical procedure.
d) Sharp wastes	Needles, syringes, blood vials, etc.
e) Wastes with high content of heavy metals	Batteries, broken thermometers, blood-pressure gauges, etc.
f) Hazardous wastes	Wastes that are subject to special handling because of their physical /chemical properties or legal reasons such as hazardous chemicals.
g) Pharmaceutics wastes	Waste entailing pharmaceuticals that are expired or no longer needed; items contaminated by or containing pharmaceuticals (bottles, boxes).
h) Radioactive wastes	Waste containing radioactive substances (e.g. unused liquids from radiotherapy or laboratory research; contaminated glassware and packages).

The teams formed a conceptual model (road map) to determine recycling opportunities and select the best treatment technology/technologies for waste disposal in a health care system (Fig.1).

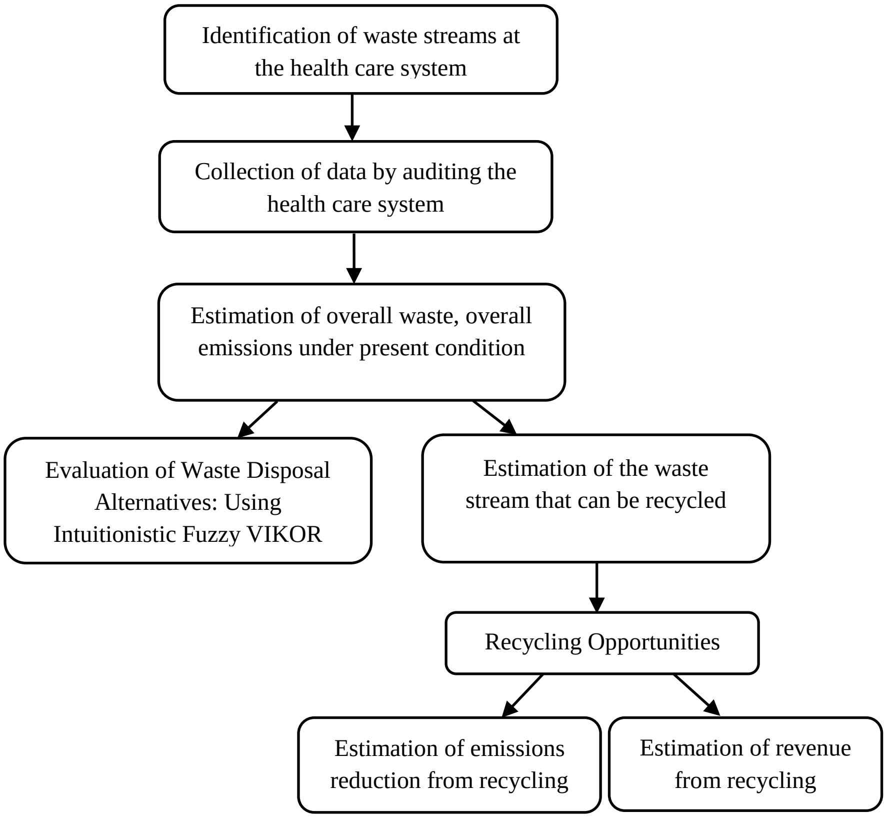

Figure 1. Flow chart of generalized model to evaluate waste disposal alternatives, recycling opportunities, GHG emission, and revenue from recycling program

The teams had several on-site visits from a hospital located in Midwest (with over 300 patients) to evaluate waste disposal alternatives. The procedure used to estimate the annual solid waste streams at this hospital involved a large sampling of waste containers in several areas (Fig.2).

Figure 2. Some samples of inspected containers

The teams also evaluated the GHG emissions generated from each material and computed the net revenue generated when all the recyclable waste components are recycled. In the next step, the teams considered the four potential treatment technologies and defined environmental, economic, technical, and social criteria (Fig.3) as follows.

A_1 : Incineration, A_2 : Steam sterilization, A_3 : Microwave, and A_4 : landfilling.

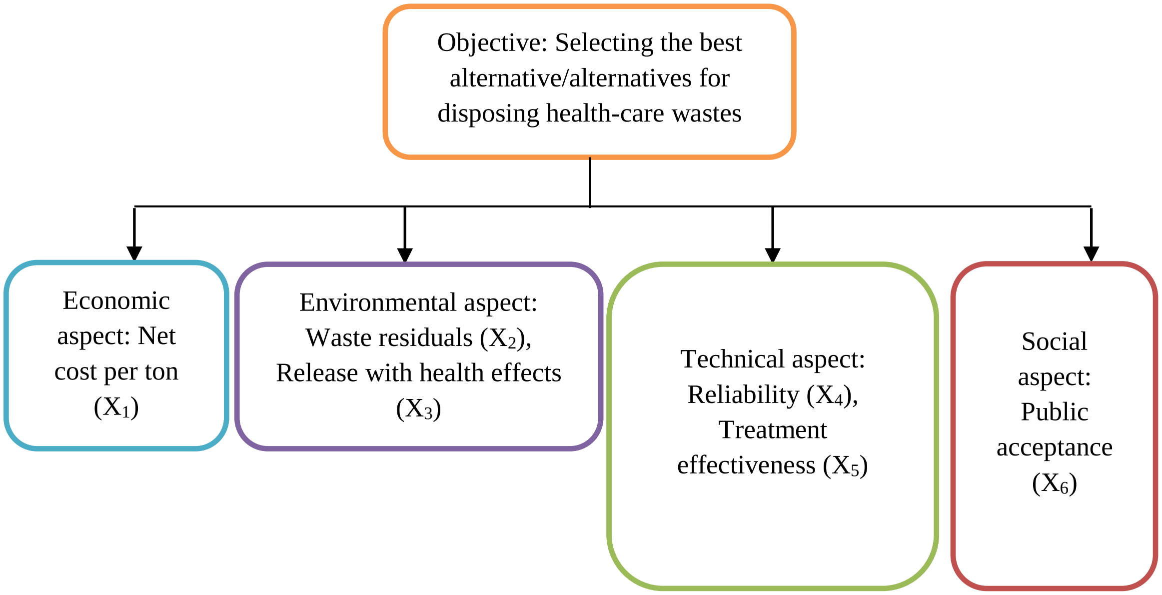

Figure 3. Defined criteria and sub-criteria for selecting the best alternative

Then, the VIKOR-based intuitionistic fuzzy MCDM method was utilized to determine the best health care waste treatment alternative. Analyzing the obtained results showed that steam sterilization and microwave technologies are the best alternatives for disposing health care wastes as they emit fewer pollutants and generate non-hazardous residues.

Data Analysis on the Student's Attitude and Performance

The course-based research project approach was intended to enhance the required a-k ABET learning outcomes by providing an opportunity for the students to work in interdisciplinary teams and solve the engineering problem for a health care system.

The hypotheses of this research defined in a way to evaluate whether "the application of a course-based research project for the Optimization course at the Purdue University Fort Wayne will:

- Improve the students' attitude towards optimization,
- Enhance the students' understanding of the relevance of subject matter to life and society
- Improve the student's ability in decision making, problem solving skills, and applying concepts

- Improve the students' self-efficacy (like, easier, emotional, self-confidence, accomplishment, responsibility, interdisciplinary)
- Enhance ease of learning the subject matter for the students
- Enhance team working for the students
- Improve communication skills for the students
- Improve the student's final grades for the course

The hypotheses were testing using the Kolmogorov-Smirnov normality test and t-tests for comparing a) the pre surveys given during the first week of the optimization course in fall 2016 and 2017 and b) the post surveys given during the last week of the optimization course in fall 2016 and 2017. The t-tests were used versus z-tests due to the sample size of 20 for each response, t-tests at the 95% confidence level were conducted to examine if there were significant differences/improvements from the pre and post assessment survey results in 2016 and 2017 and the results were compared between years. The null hypothesis (H_0) states that there was no difference between the pre and post assessment survey results for each response. The alternate hypothesis (H_1) states that there was a significance difference between the pre and post assessment survey results for each response.

A comparison of the survey results for the two offerings of the course indicated very similar pre-survey results that were not statistically different at the 95% confidence level, but the comparison of the fall 2016 classroom versus the fall 2017 classroom post survey indicated statistically significant improvements at the 95% confidence level. As displayed in Table 2, the students' mean scores in post survey responses for the fall 2017 classroom has significantly increased. These results indicate that the fall 2017 classroom approach provided better outcomes in terms of student attitudes and self-efficacy.

Table 2. Post Survey Comparison between Course Offerings (Scale Likert 5 points)

Question	Fall 2016		Fall 2017		t Test Statistic	Analysis of Hypotheses at the 95% Confidence Level
	Mean	Std. Dev.	Mean	Std. Dev.		
1. The instructional materials, class activities, labs, assignments, and the research project were integrated in a way that made my learning easier	2.86	0.89	3.89	0.90	21.80	H0 rejected and H1 Accepted
2. The instructional materials and research project emotionally engaged me in learning the course topics	2.54	0.99	4.12	0.86	135.48	H0 rejected and H1 Accepted

3. The instructional materials and research project involvement increased my self-confidence	3.14	0.78	3.91	0.86	14.32	H0 rejected and H1 Accepted
4. I achieved a sense of accomplishment in learning by using the instructional materials and working on a research project with teams	2.16	0.94	3.79	0.84	72.12	H0 rejected and H1 Accepted
5. The instructional materials and involvement in a research project helped me assume a greater responsibility for personal learning	2.56	0.88	3.96	0.84	38.54	H0 rejected and H1 Accepted

Additionally, the average final grades in the course increased by 14.2% (statistically significant at 95% confidence level, t Test statistic=4.48; n_1 and n_2=20, H_0: there was no difference between the final grades in fall 2016 and 2017. H_1: there was a significance difference between the final grades in fall 2016 and 2017) and the standard deviation remained similar.

Table 4. Final Grade Comparison

	Mid-Term Exam		Final Grade	
Year	Average	Standard Deviation	Average	Standard Deviation
2016	81.3	6.9	85.6	4.2
2017	89.6	5.5	91.4	3.8

Conclusion

The application and implementation of the course-based research project and real case study to the optimization course proved to be a value-added addition and will be included in future offerings of the course. The approach enhanced the learning experience by improving the attitudes of the students toward the subject matter and highlighting the relevance to society and the community. Some limitations of the study include the location and sample size. A larger, more diverse sample would provide broader results. Further analysis of the course-based research project classroom approach in multiple setting would provide deeper insights into this area.

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Appendix A

<u>Assessment of Project Report</u>

Max Score = 120

Reviewer's Initial: ______________________________________ Date: ______________

Name of Student: ______________________________________

Title: ______________________________________

Writing Communication

(decimal scores are allowed)

Performance Criteria	Wt.	Total Score	Score	A	B	C	D	F
				4	3	2	1	0
Report writing is clear and concise.	2			Report is to the point, clear, and concise. Coverage is good.	Report sometimes deviates from the subject. Coverage is adequate.	Report deviates from the subject. Coverage is not adequate.	Report is vague. Coverage is poor.	Report not written
Report is well organized and easy to follow.	2			Good headings. Appropriate paragraphs. Followed formatting instructions.	Appropriate headings. Long paragraphs. Missed some instructions.	Few headings. Long paragraphs. Missed many instructions.	No headings. Long paragraph. Missed all instructions.	Report not written
Report is written in professional language and style.	3			Proper words used. Written in third person. Good Exceptional.	Some improper word used. Written in third person. Good.	Frequently improper words used. Written in first person. Fair.	Frequent improper words used. Written in first person. Needs improvement.	Report not written
Report free of typographical errors.	1			0 errors.	1 to 3 minor errors.	4 to 5 minor errors.	6 to 7minor errors.	8 or more errors
Use of appropriate technical literature.	2			Appropriate and current technical literature used.	Appropriate but older technical literature used.	Appropriate but outdated technical literature used.	Inappropriate technical literature used.	Not given in the report
Outcome *g1* score Max=40			<u>Comments:</u>					

Professional Development

Performance Criteria	Wt.	Total Score	Score	A 4	B 3	C 2	D 1	F 0
Use external sources in course/project work	5			Reliable external sources used.	External sources used.	Some external sources used.	Internal sources only used.	No sources used at all.
Outcome *h* score Max=20			Comments:					

References

Performance Criteria	Wt.	Total Score	Score	A 4	B 3	C 2	D 1	F 0
All references cited in the written work	5			All references cited clearly in the text.	Most references cited in the text.	Some references cited in the text.	Few references cited in the text.	None cited.
Outcome i_1 score Max=20			Comments:					

Creativity in Design

Performance Criteria	Wt.	Total Score	Score	A 4	B 3	C 2	D 1	F 0
Select a well-defined problem for project.	4			Project description is clearly defined and explained.	Project description is clear but needs explanation.	Project description not clear and needs explanation.	Project description is not clear at all.	Project not done.
Design using proper knowledge and skills.	4			All knowledge and skills were used.	Some relevant knowledge and skills were not used.	Important knowledge and skills were not used.	Irrelevant knowledge and skills were used.	Project not done.
Design creatively and accurately.	2			Very creative in design.	Reasonable creativity is shown in the design.	Little creativity is shown in the design.	Textbook application in the project design.	Project not done.
Outcome *d* score Max=40			Comments:					

Overall Project Score Max=120		<u>Overall Comments:</u>

Appendix B

<u>Assessment of Student Presentation</u>
Max Score = 40

Name of Student: ______________________________________ Date: ______________

Start time: ____________ Finish time: ____________

(decimal scores are allowed)

Performance Criteria	Wt.	Total Score	Score	A	B	C	D	F
				4	3	2	1	0
Presentation includes introduction, body, conclusions, and references.	2			They are given very clearly. Time spent on each was adequate.	They are fairly clear. Time spent on one was short.	They are just clear. Time spent on two or more was short.	They are barely clear. Time spent on all three was short.	Not done.
Student communicates clearly.	3			Communicates very clearly. Eye contact is good.	Clear but some "ums". Eye contact is ok.	Sometimes hard to hear. Read from script.	Mumbled most of the time. Often had back to audience.	Not done.
Student has well-prepared audiovisual materials.	2			Slides well prepared. All slides were clear.	Slides well prepared. Few slides not clear.	Slides were ok. Most slides not clear.	Poor slides. Hand drawn sketches.	Not done.
Student responds effectively to questions & comments.	2			Most questions answered correctly and confidently.	Most questions answered but lacked confidence.	Answers were weak or not in sync with questions.	Could not answer questions. No time for Q&A	Not done.
Student dresses appropriately.	1			Dress was appropriate for technical presentation. Exuded confidence.	Dress was acceptable for technical presentation. Confidence was adequate.	Dress was casual. Confidence was weak.	Dress was very casual. Did not take the subject seriously.	Not done.
Overall Score			<u>Comments:</u>					