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Work in Progress: Research-based Teaching in Undergraduate Thermofluid Mechanical Engineering Courses in a Primary Undergraduate University

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RESEARCH-BASED TEACHING IN UNDERGRADUATE THERMOFLUID MECHANICAL ENGINEERING COURSES IN A PRIMARY UNDERGRADUATE UNIVERSITY

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Abstract
This paper presents the author's approach to use open-ended research and design projects as supplement to traditional teaching in undergraduate thermofluid mechanical engineering courses. It is widely accepted that teaching and research in higher education, especially in engineering programs, should support and supplement each other. This is more important and challenging for undergraduate programs where traditionally more emphasis is placed on teaching. Furthermore, the knowledge student gained during the course of their education is to prepare them for solving real world problems and research can be the best tool to train them for this purpose. Based on the belief that research should heavily involve undergraduate students, the integration of research to teaching has been one of the primary objectives of the author since fall 2011 when he joined a primarily undergraduate institution until 2017. This has been very challenging due to the teaching oriented traditions of the school, the lack of graduate students to support undergraduate research, the heavy teaching loads of faculties, and the lack of the research infrastructure. To achieve this objective and overcome barriers, a new element namely the research project, was added to most thermofluid courses that the author taught. Most students have shown great interest in these research projects and typically performed very well above and beyond expectations. Between 2012 and 2017, the students have published/presented 44 refereed conference papers and 36 posters involving about 190 students as coauthors at various conferences. Also, about 110 students attended and presented papers or posters they prepared in 13 conferences in the USA and Canada. This manuscript will explain the procedures and approaches used, and some of the outcomes.

Introduction
A brief review of the history of engineering education indicates that until mid-20th century engineering students were trained in whole or in part through apprenticeships and practice. However, after WWII the complexity of engineering systems, which required deep theoretical understanding, led to increase in theoretical contents. This inevitably resulted in sacrifices of skill-based contents [1, 2]. Therefore, the main objective of engineering education became transferring of the body of knowledge rather than developing skills. By the late 20th century, significant pressure was placed on universities from various stakeholders, including accreditation bodies, employers, and professional societies, to increase practical aspects of engineering education. They reasoned several problems including "insufficient preparation for research and creation; excessively theoretical instruction with a reduced practical component; knowledge that

is too general with deficient specialization and updated knowledge; and meagre preparation in directing human teams” [3]. They pushed for the “balance between theory and practice in engineering education” [2].

This environment led to various alternative learning styles, such as active learning, problem-based learning, experience-based teaching, experimental-learning, research-based teaching, and project-based learning. These teaching-learning approaches are typically interaction-oriented compared to the transmission-oriented nature of traditional methods. These approaches have a lot in common [1] and sometimes distinguishing them is not easy. The project-led education has been very popular in engineering programs since the 1990s [2]. The project-based learning is extensively being used for teaching engineering design through capstone or senior design courses. This is partly due to requirements of accreditation bodies [2].

Considering the fact that teaching and research are two most important functions of higher education systems, the integration of them has been an attractive idea. However, as reported by Healey [4], there are strong feeling among academicians on relationship between research and teaching. While some believe “university research often detracts from the quality of teaching”[5], other stated “courses taught by those at the cutting edge of research will necessarily be of higher quality than those taught by those merely using the research results of others – whatever the apparent quality of their style of delivery” [6]. However, some researchers reported “no significant relationship between research productivity and teaching effectiveness” [7].

The boundary between project-based and research-based teaching-learning has not been defined clearly. Hosseinzadeh and Hesamzadeh defined project-based learning (PBL) as “a learning environment in which projects drive learning” [8]. Rois et al. described the three stages of project-based learning development in the period of twenty years [3]. These two terms sometimes are used interchangeably. In this paper, the main focus is on the research-based approach which is distinguished from the project-based approach by their ultimate objective. While in the project-based approach the objective is to create a product (a physical product or a design for a product), in the research-based approach the objective is to conduct research aimed at preparing some sort of publications or presentations. However, both approaches involve activities that aim at professional practices and contextualization of learning for real world situations. These teaching approaches not only consider technical factors but the integration of those factors with social, economic, legal, and many other factors [9].

These two student-centered learning approaches are typically involved variety of activities aimed at all or some of the following skills:

- problem solving
- critical thinking
- teamwork
- creativity
- communication skills
- conflict resolution
- project management

- leadership
- idea creation
- professional commitment
- autonomy
- interpersonal skills

In these activities students take initiatives to solve a large-scale open-ended real world single or multidisciplinary problem, to produce an end product (prototype, report, program, etc.) during a considerable time period, with a specific deadline [10, 11].

Implementation of research-based teaching-learning approach

The author had taught at a primarily undergraduate university between 2011 and 2016. Based on the belief that research in higher education should heavily involve students and the fact that no graduate students was available in the school to conduct research, integration of the research to teaching was one of the author's primary objectives in that period. Furthermore, the knowledge student gained during courses is to prepare them for solving real world problems when they start their career as an engineer. To achieve these two objectives, between fall 2012 and fall 2016, he added a new element, namely research/design project, to most courses that he taught, particularly thermofluid courses. The objective of these research/design projects was to provide students with an opportunity to apply their overall engineering knowledge, especially in the specific topic of the course combined with their innovation to solve an engineering problem.

For this purpose, the following three items were added to the course "Expected Learning Outcomes":

"After successful completion of this course the students will be able to:

1. Review the literature on the selected topics of interest in thermodynamics.
2. Apply the gained knowledge and skills in the course to solve an engineering problem.
3. Prepare scientific/engineering reports in a professional manner."

Also, the following statement was added to the "Course Objectives": "… through design/research projects, the students will learn to review the literature on the selected topics of interest in thermodynamics and apply their knowledge to solve a real world engineering problem. Also, they will be able to prepare scientific/engineering reports in a professional manner."

Before describing the used approach by the author, it should be noted that while these new teaching-learning approaches have been very popular, there have been some research that cast very significant and serious doubt on their effectiveness. For example, Kirschner et al [12] stated that "these [minimally guided] approaches ignore both the structures that constitute human cognitive architecture and evidence from empirical studies over the past half-century that consistently indicate that minimally guided instruction is less effective and less efficient than instructional approaches that place a strong emphasis on guidance of the student learning process." [12] They categorized "discovery learning, problem-based learning, inquiry learning, experiential learning, and constructivist learning" as the minimally guided approaches. They believed these approaches might be only effective if "learners have sufficiently high prior knowledge to provide "internal" guidance" [12]. Because of this uncertainty, while sometimes the research/project-based approach have been used as the main learning method [10], in the author's courses, the method was used as a supplementary approach combined with traditional and other alternative learning approaches.

To implement the research/design project element, the author provided a list of potential projects related to the topic of the course, commonly related to his research interests, for the students to choose from. Alternatively, they could propose their own topic of interest and work on it after the instructor's approval. They were expected to prepare three reports: proposal, interim report, and final report as well as a final poster and an oral presentation. The students should follow the given instruction when preparing all deliverables. All reports and other related documents should be uploaded to Google Drive file repository that was provided to them. They could receive bonus grade for submitting a scientific paper and poster presentation to a conference. For most deliverable documents, the students were provided with opportunity to review their mistakes and revise their reports. The students were asked to submit a revise version of their report as a part of the final grade for that report. These three stages of reporting were meant to mimic the actual process in the real world engineering practice. Each team ought to meet the instructor biweekly to report the progress in the project and to discuss future plans. The number of students per group depended on the topic of the project and its scope.

The topics and the scope of the projects depended on the course and expected time that students were supposed to spend on the project. For two consecutive semester courses, e.g. Thermodynamics and Applied Thermodynamics (six credit hours together) and large teams, projects were typically more substantial and complex, such as:

- design, fabrication, and experimentations,
- numerical model development and sensitivity/optimization analyses.

For typical single semester thermofluid courses, they were smaller projects in several formats, including:

- data gathering and evaluations for many case studies,
- sensitivity analyses and optimization of existing numerical models.

In order to provide an appropriate environment for students to conduct their research, the author established the Energy Sustainability Research Laboratory (ESRL) and collaborated with other colleagues to establish the Fuel Cell Research Laboratory at West Virginia University Institute of Technology. These two labs were equipped with the following experimental setups:

- Wind energy: Small scale horizontal and vertical axis wind turbines and weather station to record local wind data to estimate wind energy (Figure 1)
- Fuel cell: Polymer electrolyte fuel cell (PEFC) electro-catalyst, membrane electrode assembly (MEA), and stack manufacturing equipment; PEFC experimentation and analysis setup, solid oxide fuel cell (SOFC) experimentation and analysis setup (Figure 2)

- Photovoltaic solar panel setup and pyranometer (to measure solar energy) (Figure 1)
- Internal combustion engines with hydrogen enhanced combustion (HHO)
- Vehicle onboard hydrogen generation
- Biodiesel-fueled internal combustion engines

Figure 1: Residential wind turbines (both horizontal and vertical wind turbines), solar PV units, and weather station installed on the roof of the engineering building

Figure 2: Fuel cell demonstrational units

Other than the experimental research in the labs, the students conducted some numerical modeling and feasibility analyses, including:

- Modeling of power generation systems: compressor inlet air cooling systems for gas turbines and combined cycle power plants, ocean thermal energy convertors (OTEC), and CO_2 capture systems (Figures 3 and 4)
- Design and fabrication of a hydrokinetic energy conversion system
- Design and building a microalgae photobioreactor for CO_2 capture (Figure 5)
- Horizontal axis wind turbine: Increasing power by addition of a shroud and diffuser
- Ocean renewable energy resources in the oceans surrounding the United States: wave, tidal, and thermal energies
- Ground source heat pump using abandoned coal mines
- Greenhouse gas emission reduction potentials: West Virginia case study
- Maximization of power production at small dam hydroelectric power plants
- Adding hydro power plants to existing dams: case study of Summersville, Bluestone, and London Dams
- Fabrication and experimental analysis of gasification systems for transportation application (Figure 6)

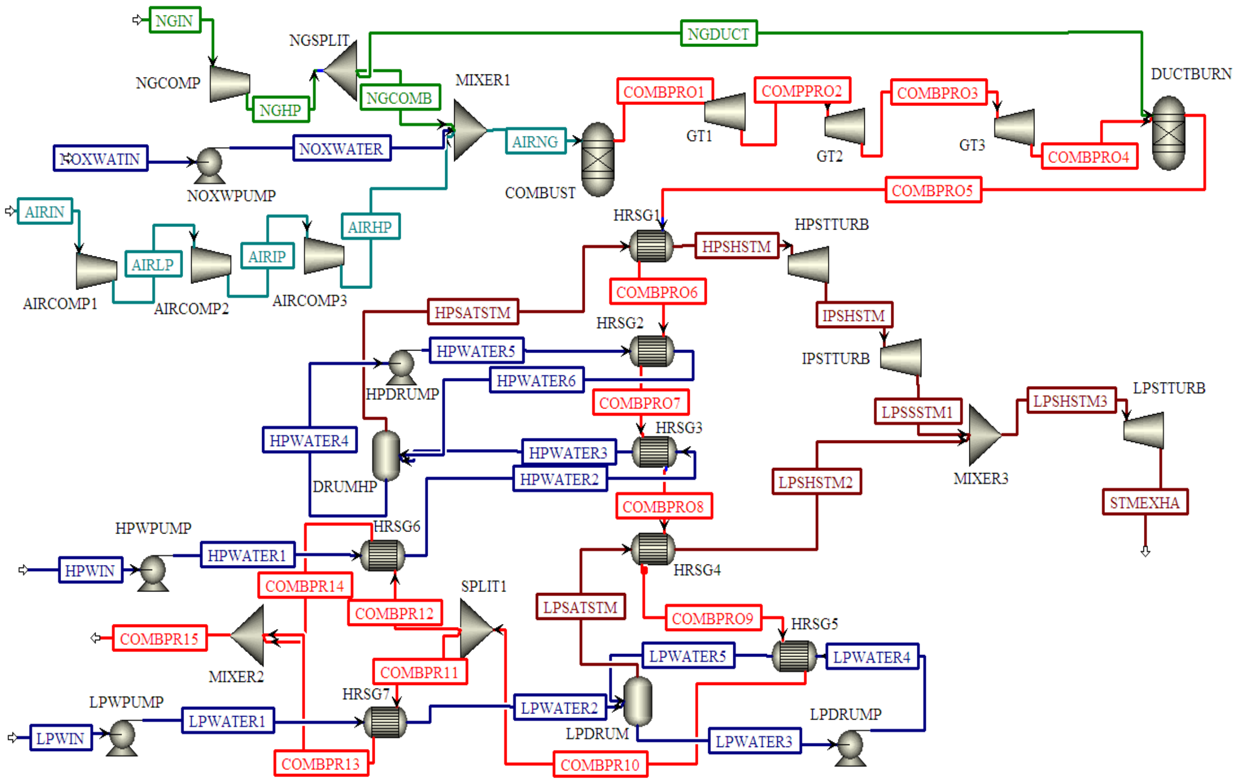

Figure 3: Schematic of an Aspen Plus® model of a two-pressure combined cycle power plant (CCPP)

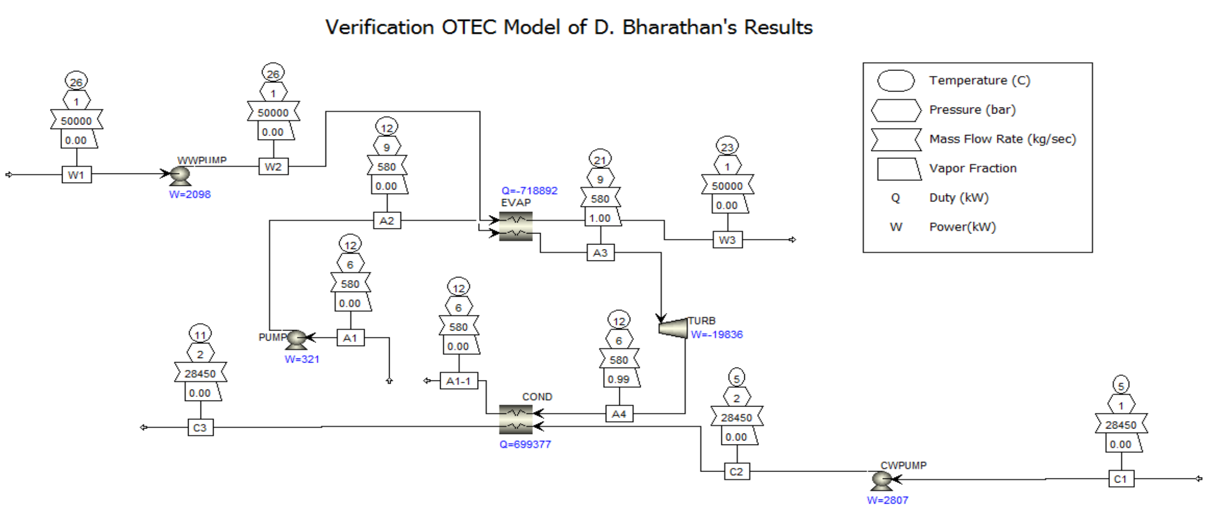

Figure 4: ASPEN Plus Model of ocean thermal energy conversion (OTEC)

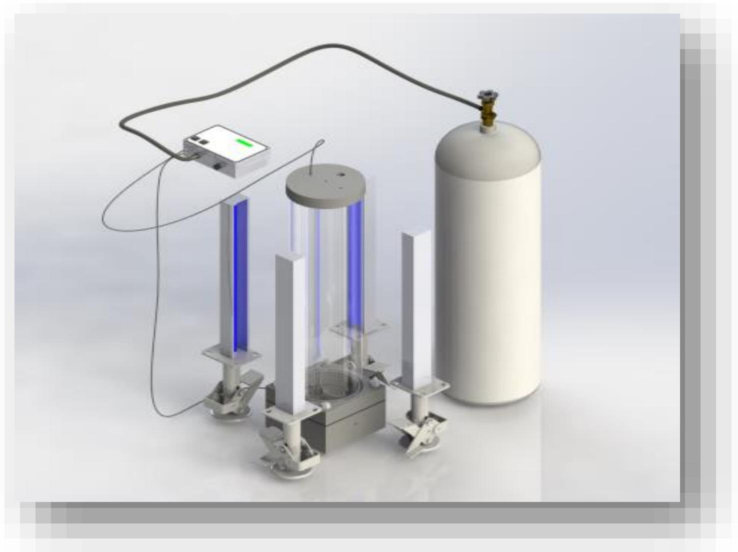

Figure 5: Schematic of the bubble column CO_2 capture unit utilizing miceeroalgae

Figure 6: Biomass gasifier-based engine

One source to create smaller projects was the senior design (capstone) course. The author taught the senior design course for several years and used the projects developed in the course for research projects in his thermofluid courses.

The approach explained above was evolved from several trial and errors. In one of the early trials, the author used the same topic for the entire class. For example, he used the following project statement for his Fluid Mechanic course:

“Water is essential for living and the shortage of water is one of the main challenges of the future. In this semester-long project, you will conduct a literature review on the water conservation methods and identify various methods to attack the problem. Then, you will be guided step by step to design a water conservation system for your house. For this project, you need to form a team of two or three students. Each team should select a house/building that they have unlimited access to. If you do not have access to any building and could not team up with someone who has, advise the instructor.”

While this method was effective to directly apply the topic of the course in the project, it lacked the crucial elements of creativity and independent research.

In another attempt, the author tried to introduce two independent projects on different subjects: one literature review topic and one research topic. The following statement was used for the former part:

“As a first step in approaching any engineering problem/project, you need to know what other people have done in similar situations; thus, you do not need “to reinvent the wheel again”. You can learn from their mistakes and avoid repeating the same mistakes. Also, you can identify various options and choose the best one for your case and try to improve and optimize it. The objective of this type of project is to provide you with an opportunity to practice this vital skill.”

This approach was not successful due to the amount of the work involved and the time students should spend on the projects.

Everything students did or prepared, including major reports, progress reports, information from literature, etc. were expected to be uploaded to Google Drive. This practice had several major benefits. The most important impact of this practice was that the knowledge and experience student gained in their project accumulated and stored in a single location. The students working on the same topic had access to the folder as well as the instructor(s). When new students started to work on the same topic, the Google Drive folder from past teams was shared with them and they had access to everything the previous team(s) had done and used.

The final overall course assessment was according to the following items:

- Proposal 15%
- Interim report 15%
- Final report 30%
- Progress reports or meetings 20%
- Poster 15%
- Oral/PowerPoint presentation 5%
- Bonus for submitting a scientific paper and poster presentation to a conference 30% and 25%, respectively.

Depending on the course and the scope of the projects, the entire project made 30-35% of the course grade.

Discussion and conclusion

The students have shown great interest in these research topics and typically performed very well. Between 2012 and 2017, the students has published/presented 44 refereed conference papers involving 94 students as coauthors at various conferences. Also, about 110 students attended and presented papers or posters they prepared in 13 conferences in the USA and Canada, including ASME International Conference on Energy Sustainability; ASME Fuel Cell Science, Engineering and Technology Conference; Canadian Congress of Applied Mechanics; American Society for Engineering Education (ASEE) North Central Section Conferences; ASME Early Career Technical Conference; The Science, Technology and Research (STaR) Symposium; and International Conference on Energy Systems. They also presented 36 posters involving 96 students. It should be noted that these publications and their research have been based on the student research in both typical thermofluid courses and capstone projects and in some of them the students had co-advisors. Initially, the author had a difficult time to convince the students that undergraduate research is important for their career. This was evident in students' unwillingness to attend conferences to present their work. But later the research culture was gradually established in the department and the students had recognized the value of research for their education. For example, seven students attended 2016 American Society for Engineering Education (ASEE) North Central Section Conference in March 2016 in Mt Pleasant, Michigan to present five papers. In fact, since 2013-17, over 100 mechanical and civil engineering students attended and presented papers and posters they prepared.

The key in persuading students to publish and present their work is to provide wide and diverse opportunities for them to present at various platforms and events, from university events (e.g. the design expo) to local events (e.g. undergraduate research day) to national and international conferences. Depending on the quality of the research students conducted, the available fund from the university to support student travels, the students ability to self-support their travels, and the timing of the event, they could choose the best avenue appropriate for them and their project.

Among various steps to complete the projects, the proposal preparation stage was the most challenging step for most projects. The students needed most help during this step. If they could make the proposal right, they had a very high chance to be successful in the overall project. It was imperative and worthwhile to spend as much time as required on the preparation of the proposal. This typically paid-off by the success of the project at the end.

Another major challenge was how to relate covered material in the course to the implementation of the project. This was particularly difficult when students worked on their own proposed projects. In these cases, often the instructor had to interfere to include some direct or indirect experiments or analyses related to the course topics.

The teaching oriented traditions of the school was also a major obstacle. Convincing the administrations of the effectiveness of this approach was not easy, at least until the benefits became obvious. The lack of research infrastructure in the school to support these efforts made the process even more challenging.

The importance of providing continuous feedback on three major reports cannot be overstated. Providing feedback to the first draft of the reports and expecting the second draft with the comments incorporated into the report resulted in a good final report that could be used as a solid based for preparing publications.

The most fruitful experience was when students continued to work on a project or related topic on for a longer period particularly for their capstone project to achieve more substantial results.

In several cases, conducting the research and presenting the outcomes encouraged the students to go to a graduate program. They were students who otherwise would not have pursued their education in the graduate level.

The lack of graduate students to support undergraduate research caused a huge time commitment for the instructor. The heavy teaching loads of faculties was also a hurdle. Therefore, the success of the described process highly depended on the class size and most suited for small size classes, say less than 20 students. For larger classes, the author is currently developing a research methodology and communication course for undergraduate students.

Finally, dealing with how to present the publications in the instructor’s annual report and promotional package is a very delicate matter. In order to determine if they should be considered as teaching or research contributions, it is strongly advised that the faculty coordinates with the department chair.

References

[1] McDermott, Kevin J., Andrew Nafalski, and Ozdemir Gol. "Project-based teaching in engineering programs." *Frontiers In Education Conference-Global Engineering: Knowledge Without Borders, Opportunities Without Passports, 2007. FIE'07. 37th Annual*. IEEE, 2007.

[2] Dutson, Alan J., et al. "A review of literature on teaching engineering design through project-oriented capstone courses." *Journal of Engineering Education* 86.1 (1997): 17-28.

[3] de Los Rios, Ignacio, et al. "Project–based learning in engineering higher education: two decades of teaching competences in real environments." *Procedia-Social and Behavioral Sciences* 2.2 (2010): 1368-1378.

[4] Healey, Mick. "Linking research and teaching exploring disciplinary spaces and the role of inquiry-based learning." *Reshaping the university: New relationships between research, scholarship and teaching* (2005): 67-78.

[5] Pocklington, T. and Tupper, A, (2002) *No Places to Learn: Why universities aren’t working*. Vancouver: University of British Columbia Press.

[6] Lee, R. (2004) Research and teaching: making – or breaking – the links, *Planet*, 12: 9-10.

[7] Hattie, J. and Marsh, H. W. (1996) The relationship between research and teaching: A meta-analysis, *Review of Educational Research* 66(4): 507-42.

[8] Hosseinzadeh, Nasser, and Mohammad Reza Hesamzadeh. "Application of project-based learning (PBL) to the teaching of electrical power systems engineering." *IEEE Transactions on Education* 55.4 (2012): 495-501.

[9] Luxhøj, J.T. and Hansen, P.H.K., Engineering curriculum reform at Aalborg University. *J. Engng Educ.*, 1996, **85**(3), 183–186.

[10] Lima, Rui M., et al. "A case study on project led education in engineering: students' and teachers' perceptions." *European journal of engineering education* 32.3 (2007): 337-347.

[11] Helle, L., Tynjälä, P. and Olkinuora, E., Project-based learning in post-secondary education—theory, practice and
rubber slings shots. *Higher Ed.*, 2006, **51**(2), 287–314.

[12] Kirschner, Paul A., John Sweller, and Richard E. Clark. "Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching." *Educational psychologist* 41.2 (2006): 75-86.