



Enhancing undergraduate education through research-based learning: a longitudinal case study

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Abstract

Various surveys of employers about college graduates have revealed three major complaints: poor writing and verbal skills, inability to problem-solve, and difficulties working collaboratively with other professionals. This can be partly attributed to the traditional lecture-based instruction students typically receive throughout their college education. Often, students are not effectively motivated to grasp the course materials and fail to connect them to the real world. An alternative student-centered, inductive approach involving active and cooperative learning could better motivate the students and help to transform them from passive recipients of other people's knowledge into active constructors of their own and others' knowledge. Two effective methods of student-centered teaching include active/collaborative learning and inductive teaching and learning (ITL). Based on my experience of supervising 16 undergraduates on a collaborative biomedical research project over the past four years, a research-based learning (RBL) model has been developed that makes important addition to current ITL methods.

The proposed RBL model shares some of the common features of ITL in that it is a student-centered and process-centered inductive approach. It also has the following features that distinguish itself from the other ITL methods: (1) A relatively longer duration and amount of time a student is involved in the research project; (2) A clearly defined research scope and objective; and (3) Promotion of both teamwork and individual excellence. This paper describes how I leveraged my own background and student interest to initiate the collaborative research project, how undergraduates participated in the research project through different avenues, and how the experience enhanced their skills in critical analysis, problem-solving, communication and teamwork, which positively impacts their career, regardless of whether they pursue an industry job or an academic position after graduation.

Some practices I have been promoting in undergraduate research, such as literature review, summary and critical analysis, note taking, and dissemination of results have been shown to be effective in enhancing the students' research skills with productive research outcome. The research project conducted by the 16 undergraduates has so far yielded one journal article, one manuscript in review, one in preparation, and six conference presentations/posters. Seven of the 16 students went on to pursue a graduate degree. All 16 students reported positive impact of undergraduate research on their career, as shown in the alumni survey results.

Student-centered learning

Today's knowledge-based economy driven society asks for highly skilled young people at all levels. Over 80% of the jobs posted online requires at least a bachelor's degree¹. According to a survey by the Chronicle of Higher Education and the American Public Media's Marketplace, a degree is more important than ever to employers. On the other hand, half of the employers surveyed complained of difficulty in finding qualified job candidates. Thirty-one percent of

employers indicated that recent graduates are unprepared for their job searches². There is a big skill gap between employer needs and what graduates have, especially on communication and problem-solving. This is consistent with the findings from the earlier Wingspread Conference Report³. At the conference, leaders from government, corporate, philanthropic, higher education, and accreditation communities identified a list of characteristics of quality performance important for college and university graduates: high-level skills in communication, computation skills, ability to define problems, gather and evaluate information and develop solutions (critical thinking), motivation and persistence, technical competence, ability of work with others (teamwork), and use all of the above characteristics to solve problems in complex, real-world settings (problem-solving). All this calls for reforms in higher education learning and teaching process in order to help students better develop these core competencies and dispositions for entry into the global knowledge-based economy.

The past two decades have seen a steady but evident transition of higher education from the traditional lecture-centered instruction to the student-centered approach. The traditional education is usually deductive, beginning with theories and progressing towards applications. Often students are not effectively motivated to grasp the course materials and fail to connect them to the real world. An alternative student-centered, inductive approach involving active and cooperative learning could better motivate the students and help to transform them from passive recipients of other people's knowledge into active constructors of their own and others' knowledge. Commonly used student-centered learning methods include active learning, cooperative learning, collaborative learning, and inductive teaching and learning (ITL). ITL also encompasses a range of instructional methods including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching^{4,5}.

The Kern Entrepreneurship Education Network (KEEN) was created by the Kern Family Foundation in 2005 as a collegiate initiative to increase the quantity and quality of U.S. engineering talent, specifically by integrating the entrepreneurial mindset into engineering education. There are seven student outcomes pertaining to the entrepreneurial mindset⁶:

1. Effectively collaborate in a team setting
2. Apply critical and creative thinking to ambiguous problems
3. Construct and effectively communicate a customer-appropriate value proposition
4. Persist through and learn from failure to learn what is needed to succeed
5. Effectively manage projects and apply the commercialization process (within respective disciplines)
6. Demonstrate voluntary social responsibility
7. Relate personal liberties and free enterprise to entrepreneurship

Lawrence Technological University (LTU) is one of the first participating KEEN institutions. Along with Boston University, Saint Louis University, Kettering University, Worcester Polytechnic Institute, and Gonzaga University, they form the Dynamic Compass Network (DCN) that focuses on faculty excellence, curricular innovation, peer collaboration, and experiential learning. The KEEN program provides funding at different levels (institution, topical and small group) to serve as catalyst in transforming the undergraduate engineering education and infusing students with the entrepreneurial mindset. Part of the DCN is to incorporating

active/collaborative (ACL) and problem-based learning (PBL) into existing engineering courses. Selected as a Kern Innovative Teaching (KIT) faculty, I attended workshops to learn good practices of teaching entrepreneurial mindset, and designed and implemented new ACL and PBL modules in my courses. The experience also helped me in developing the new research-based learning (RBL) model as another student-centered learning method to enhance student skills in communication, critical analysis, problem solving and teamwork.

Research in a primarily undergraduate institute (PUI)

A primarily undergraduate institute, or PUI, is defined by the National Science Foundation (NSF) as an accredited college and university (including two-year community college) that awards 20 or fewer doctoral degrees in all NSF-supported fields such as engineering⁷. Twenty-seven percent of the 2153 PUI-eligible institutions award bachelor's degrees and are largely private⁸. These institutions usually place a strong emphasis on teaching with a heavier course load for faculty members compared to those in research intensive institutions.

Over the past several years undergraduate research in PUIs has attracted a great deal of attention. Undergraduate research has been identified as one of the ten high-impact educational practices⁹. Undergraduate research in a PUI such as LTU has its unique characteristics with natural integration of research and education, direct benefits to the participating students, and positive impact on all students, the program, college and university^{10,11}. Limited facilities, resources and staff support are major challenges when conducting undergraduate research in a PUI environment.

The past several years have seen more and more successful examples of undergraduate research led by PUI faculty members. "Best practices" identified from these groups include an appropriate topic of study, clearly defined individual goals, close faculty involvement, continuity of team members, final documentation of individual results and ongoing knowledge base¹².

With extensive research experience from my Ph.D. and postdoc training, I strived to integrate my research agenda and educational goals by actively involving undergraduates in research projects since joining the biomedical engineering (BME) program at LTU in 2008. I have been supervising a total of six undergraduate research projects. A common feature of all these projects is that they are collaborative team projects involving at least 2 BME undergraduates.

A tissue engineering research project

The ligament tissue engineering research is the biggest undergraduate research project I have supervised, in terms of the duration, the number of the students involved, and the impact on student learning and career development. It started in the spring of 2010. Tristan Maerz graduated from the BME program at LTU in 2009. He showed strong interest in biomaterials and tissue engineering research from the courses I taught where I shared my previous research experience in these areas. After graduation, Tristan was hired as a research engineer in Dr. Kevin Baker's Orthopedic Research Laboratory in William Beaumont Hospital while also starting his graduate study at Wayne State University. With support from Dr. Baker, Tristan approached me and proposed to start a collaborative ligament tissue engineering project. Three BME students

started the project from designing and building a bioreactor that can output cyclic mechanical stimulation for a tissue engineering construct. The students each logged in approximately 10 hours per week during a two-semester period. They did not receive financial compensation for the time and effort they spent on the project; instead, they received a total of 5 course credits as their senior design.

This model has since been used by 4 student teams in subsequent years, as shown in Table 1. Each team took on a subtopic to continue/expand our ligament tissue engineering research, such as scaffold material selection and synthesis, biomechanical testing, biocompatibility evaluation, electrospun fiber braiding, scaffold surface modification, and drug-containing nanofiber electrospinning. While supervising these student teams, I also established new collaboration with researchers at the University of Michigan and in surrounding institutions. These collaborators have been instrumental in this research project, providing not only resource and facility support, but also technical guidance.

Table 1. BME undergraduates involved in the ligament tissue engineering project

Name	Duration	Topic
TM	Dec 2009 - Present	Collaborator and technical advisor
YN	Jan 2011 – August 2012	Collaborator, nanofiber preparation
MS	May 2011 – Present	Nanofiber biocompatibility evaluation
AA	Jan 2010 – May 2011	Bioreactor design and construction
DB	Jan 2010 – May 2011	Bioreactor design and construction
EB	Jan 2010 – May 2011	Bioreactor design and construction
KC	Sept 2011 – May 2012	Mechanical testing
JS	May 2011 – June 2013	Mechanical testing, ESEM image analysis
AA	Sep 2013 – June 2013	nanofiber surface modification
EB	May 2012 – June 2013	Biocompatibility evaluation
RDN	May 2012 - May 2013	Nanofiber mechanical testing
CL	May 2012 – May 2013	Nanofiber braiding
MP	May 2012 – June 2013	Nanofiber surface modification
JS	May 2012 – August 2013	Nanofiber braiding
DM	May 2013 – May 2014	Drug-containing nanofiber preparation
BP	August 2013 – May 2014	Drug delivery design

Tristan has been serving as the technical advisor to all the student teams over the years. Also worthy of mentioning are Meagan Salisbury and Youssef Naim. Meagan participated in a student team in the 2011-2012 academic year. After graduation, she was also hired as a research engineer in Dr. Baker's lab, and has since become a collaborator to this project. Youssef did not participate in the tissue engineering project while at LTU. But he learned about the project from the bioreactor student team. He then worked as a technician in Dr. Joseph Corey's lab at the University of Michigan. With a strong interest in this tissue engineering project, he became the

point of contact in the collaboration I established with Dr. Corey. Many other participating students have also kept close contact with me, and often return to campus to give seminars, share their research/work experience, and offer internship opportunities to current students.

The participating students all took great pride in disseminating their research findings in the form of journal publications and conference presentations. So far the work from the five teams has led to one peer-reviewed journal publication, one in review and a third one in preparation. Each student team attended at least one local or national conference to present their work (Figure. 1). Three student teams also participated in the CUR Poster on the Hill Competition. Seven of the 16 students went on to pursue advanced degree in either graduate school or medical school. All students involved in the projects indicated positive impact of the research experience on their career, regardless of whether they pursue an industry job or academic position after graduation.



Figure 1. BME undergraduates presenting their research.

Development of the RBL model

While supervising the ligament tissue engineering project and other research projects, I have been following some of the good practices from other successful research groups led by PUI faculty members, such as literature review, summary and critical analysis, note taking, and dissemination of results. I have also been experimenting different methods with varying degree of success to enhance the student learning through research. This experience, especially with the four-year-long ligament tissue engineering project, has helped me establish a new RBL for productive undergraduate research in a PUI environment.

Figure 2 shows a typical project timeline in this RBL model. Preferably the students would be willing to start in the summer with literature review. At the first meeting with interested students, the faculty gives an overview of the research, and provides several possible subtopics to undertake as the senior design project. The faculty gives a list of journal articles (usually between 3 and 6 total) related to one topic of the project (for example, ligament injury mechanism, biomechanical properties of ligament, cell-materials interaction, mechanical stimulation, etc) to the team for review. Each student is also assigned one or two articles from the list, and is expected to thoroughly understand the assigned article(s). At the biweekly meeting, each student presents a summary of the assigned article(s), followed by discussion to compare different studies and relate them to the research project. As the students become more

familiar with the whole project, the faculty gives them more freedom to choose articles they think are of relevance to review and critique. For motivated students willing to go to campus more frequently than once every other week, the faculty can also start some lab skill training for these students in the summer.

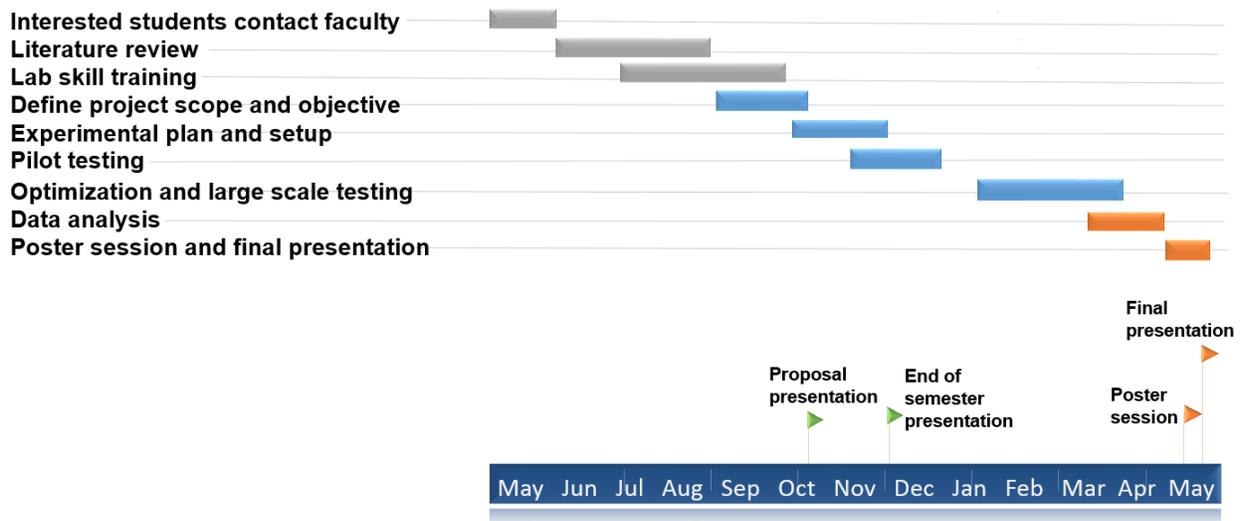


Figure 2. A typical timeline in the RBL model

At the first meeting of the fall semester, the student team decides which subtopic of the project they will work on as their senior design project. The extensive summer literature review helps the students better understand the current status and knowledge gap on many aspects of the big project. Combined with their interest and faculty input, the scope and objective of their senior design project will be defined. This process also gives the students a sense of ownership of the project.

All senior design teams in the BME program present their project proposal in early October. The research team is expected to already have a detailed experimental plan by then. They should also have completed basic lab skill training. The team will use the remaining one and half month before the semester end to work on experimental setup and conduct pilot tests. It is important for the faculty to make sure that the students start with small-scale pilot runs for each new study. These pilot runs save resources and time, and provide valuable guidance to improve the experimental design. The student team usually starts the spring semester with design modification/optimization and large-scale testing. The preparation and pilot studies conducted in the previous year will help them to be highly productive in the spring semester. The faculty holds weekly meetings with the team to be updated of the experimental progress, and to help with troubleshooting and data analysis if needed. Most of the data analysis is done as the students perform their experiments. By mid April, the students will complete all their experimental work and ready for the poster session and final presentation.

The poster session in late April consists of all graduating senior design teams from both the BME program and other life science programs at LTU. The students present their work to all life

sciences faculty and industry advisory board members. I also invite collaborators on the project to attend and provide additional comments. Many lower class students also attend the poster session and final presentation. So this provides an opportunity to attract interested students to continue the research project.

The proposed RBL model shares some of the common features of ITL in that it is a student-centered and process-centered inductive approach. It also has the following features that distinguish itself from the other ITL methods:

- a) A relatively longer duration and amount of time a student is involved: Students involved in research with the author spend a minimum of nine months on the project. Most of them would start from summer research at the end of their junior year, followed by a two-semester senior design project. The faculty usually needs to spend considerable amount of time to train undergraduates who have little research experience or skills. It is hard to expect meaningful results from a student who stays on a research project for only three months. It also provides less incentive for the faculty to find time from their already busy teaching schedule to train the students. The two-semester senior design provides a good mechanism to ensure the student is committed to the project for nine months. The students tend to be more motivated because they receive course credit for the research. The regular assignments from the senior design course (proposal presentation, end of fall semester presentation, poster, final presentation, team meeting minutes, etc) also make it easy to monitor and manage student progress.
- b) A clearly defined research scope and objective: Available ITL methods (such as PBL, case-based learning) use problems that generally have no real ownership, nor is there an actual presentation of solutions to the client. In RBL, the supervising faculty member owns the research and therefore can clearly define the scope, objective and deliverables for the research team and individual team member. For the team that starts in the summer, the faculty can give them more autonomy in defining the project scope and objective.
- c) Promotion of both teamwork and individual excellence: Available ITL methods normally have students working in teams with similar learning speed and paths. Students in the RBL model will form teams and have plenty of opportunities to practice teamwork. At the same time, each student will be encouraged to do his/her best in achieving the individual goal set by the supervising faculty and the student. For example, after completing the senior design, the students who will attend graduate school/medical school are usually motivated to write up a manuscript for journal submission, continue with some further study, or help train new students in the summer.

Impact of RBL on student learning

Undergraduates in the RBL model not only learn technical skills related to the research topic, they also practice important skills associated with entrepreneurial mindset such as critical thinking, problem solving, communication and teamwork.

The extensive literature review provides opportunities for students to practice and enhance their critical analysis skills. Each student team always run into all kinds of obstacles during the research phase of the project. They need to clearly identify the problem, come up with solutions, and utilize available resources to solve the problem. Good communication and teamwork are key to the success of an undergraduate research project. Students practice their oral and written communication skills in numerous formal and informal presentations. Two of the five teams on the ligament tissue engineering project won first place in the poster session for two years. Working in the same team for two semesters makes each student appreciate the value of good teamwork. There are different styles of teamwork. The faculty can help each team identify the role of each member, make sure every team members contribute and the opinion of each member is heard by other people in the team.

In the 2011-2013 BME program exit interview survey that includes four teams of students involved in the tissue engineering research, students made numerous positive comments about their senior design experience. Some also commended the opportunity to participate in research projects. Below are a few remarks from the alumni survey:

“My best memory of LTU was made while working on my senior design project. My team and I spent months researching, designing, and building a bioreactor for ligament tissue engineering. I really enjoyed working in the lab to finish the project. I had a huge feeling of accomplishment when the bioreactor was finally constructed!”

“I thoroughly enjoyed every second I was in the BME program at LTU! Whether it be the kind and helpful faculty or the equally nerdy and hilarious classmates I had the time of my life there. Probably the best year of college though was senior year. Completing my senior project and graduating were amazing”

“I really enjoyed my senior project. I was able to work not only with other students and professors, but also to collaborate with researchers at Beaumont Hospital and the University of Michigan. The project also afforded me the opportunity to work with the Environmental Scanning Electron Microscope recently acquired by LTU through a collaborative grant. Perhaps most importantly, the program sparked my interest in biomaterials and tissue engineering, which I am now focusing on in my graduate studies.”

Besides the obvious benefits for participating students, the ongoing research projects also provide a dynamic resource for teaching and learning. I have developed ACL or PBL modules based on the research project and implement them in classroom lecturing. Two laboratory sessions were developed for the Tissue Engineering Lab course based on the ligament tissue engineering research. All these activities contribute to my long-term goal of integrating research with education.

Sustainability of the RBL model

The sustainability of the RBL model, or maintaining a thriving undergraduate research program in a PUI environment, depends on several key factors: a support structure of funding, technical expertise and administration, and dissemination of results.

Funding: It is no secret that research funding is getting more competitive. Limited resources and time in a PUI environment adds additional hurdle to obtain external federal grants. The faculty must be flexible and creative in finding money to support the research. Besides the well-known Research at Undergraduate Institutions (RUI), Research Experiences for Undergraduates (REU), and Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES) programs in NSF, and the National Institute of Health's Academic Research Enhancement Awards (AREA) program, the faculty can seek funding from institution, industry or other private organizations. At LTU, the Kern Family Foundation provides \$15,000 per year to fund student engineering projects. Three of the ligament tissue engineering research teams each received between \$2,000 and \$3,000 for their research. The author also received funding from the LTU Faculty Research Seed Grant to support the other two teams work. LTU has recently set up the Presidential Undergraduate Research Awards to support faculty-led research projects.

Collaboration: Establishing a network of collaborators is a key component for a successful research program in a PUI environment. When seeking collaborators, it is important for both parties to see the benefit of working together. Well-defined project objective and work division, regular meetings, are good practices in maintaining productive long-term collaborations. I have had the best result when the collaborator (even in a research intensive institution) shares the same enthusiasm towards undergraduate research. Former students participating in research with the faculty can also become potential collaborators, as shown in the case study of the ligament tissue engineering project. Besides sharing their technical expertise, these students are great role models and motivate new students to undertake research. Figure 3 shows the 2012-2013 ligament research team.

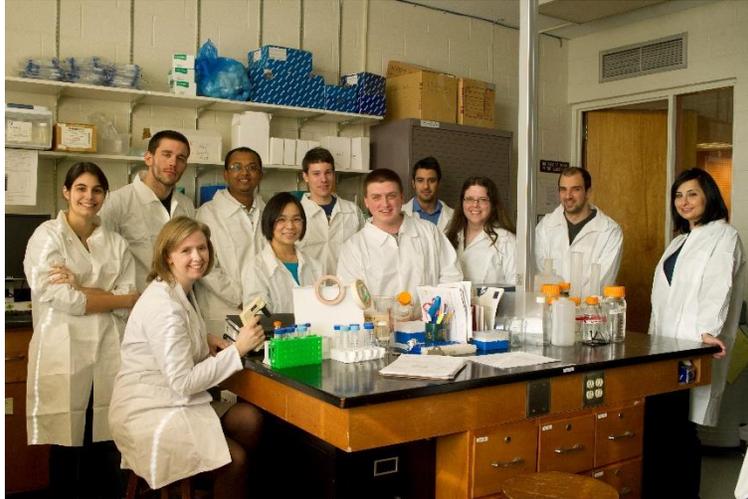


Figure 3. Ligament tissue engineering research team

Administrative support: The RBL model will be most successful in an environment where undergraduate research is valued. More and more PUIs are promoting undergraduate research and providing administrative support for participating faculty. In the College of Engineering at LTU, the two-semester senior design has traditionally been about creating a prototype based on engineering design. Allowing the BME students to conduct a research project (which does not always directly produce a tangible prototype) showed the key administrative support for me to develop this RBL model. The program director also allocated funds to partially cover expenses for undergraduate researchers to travel and present at conferences. At the institutional level, faculty-led undergraduate research is encouraged and recognized in the tenure and promotion process. The culture of supporting and celebrating research is best shown in the Annual Research Day and Presidential Colloquium every April, where faculty and students (mostly undergraduates) showcase their work in oral presentations or posters, and an invited faculty member shares his/her experience of integrated research and education.

Dissemination of results: Documenting and disseminating research data is important training for undergraduates. I always emphasize the importance of keeping lab notes and encourage students to disseminate their results in a variety of means. This ensures that the knowledge gained from one student is not lost when the student graduates. Presenting their research at local and national conferences boosts the students resume and confidence. Presenting the research studies to prospective students and their parents serves as a potential recruitment and marketing tool for the university.

Conclusions

As a high-impact educational practice, the benefits of undergraduate research are being recognized by more and more PUIs. Maintaining a productive undergraduate research program requires not only the dedication of the participating faculty, but also the establishment of a culture across campus that encourages undergraduate research and provides a network of support for the faculty.

The RBL model proposed in this paper and the case study show positive impact on student learning. Future work includes further developing this model with more direct and indirect assessment.

Acknowledgements

I'd like to thank all former and current undergraduates conducting research with me, as well as all my collaborators for providing resources and technical support. The Kern Family Foundation is acknowledged for the LEGENDS Entrepreneurial Student Awards to the undergraduate teams. I also received the LTU Faculty Research Seed Grant to support the research.

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