Incorporating Research and Design in a Community College Engineering Program

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Abstract

Traditional engineering undergraduate research and design is typically seen in four-year institutions, restricted to junior- and senior-level students. In large institutions, freshman- and sophomore-level students are generally seen to be ill-equipped to take on complex projects, particularly while muddling through the basics of calculus, physics, and electronics. Our institution, McLennan Community College, through a partnership with the Council on Undergraduate Research (CUR), has been challenging that assumption. Students are being introduced to research and design methods in the very first semester and immediately take on projects that are challenging, and most importantly, relevant to the students themselves. The preliminary results are encouraging and indicate that an early focus on research can positively impact a students' academic and professional prospects.

The Importance of Undergraduate Research for Freshman- and Sophomore-Level Engineering Students

The advantages of undergraduate research have been well-documented. Some of the most consistently-found benefits include increased retention rates and a higher likelihood of pursuing graduate education[1,4,6]. Science, Technology, Math, and Engineering (STEM) fields seem to specifically benefit from engaging their students in research and inquiry-based projects, since it has been shown that they increase students' likelihood to persist in these fields[5]. For many students, getting involved with undergraduate research is a life-changing experience, one that allows them to get excited about science and thus, clarify their career paths[7].

Most studies, however, have focused on the value of undergraduate research in general, or specifically in reference to programs targeting junior- and senior-level students. This is not all that surprising, since not too long ago research was mostly reserved for graduate students. The fact that many studies have come out in last decade listing the benefits of undergraduate research has driven a paradigm shift which has had notable positive results. However, since research projects are considered an experience ideal for the culmination of a learning experience, or the final application of gained knowledge, some may not consider research for first- and second-year students useful or worthwhile.

Recent studies have shown, however, that there is no compelling reason to limit access to research experience to upperclassmen alone. Freshman and sophomore students who have not yet acquired the key engineering, science, and math skills considered necessary can still participate and gain a lot from engaging in research. Actually, according to Bahr & Norton (2006), the earlier a student participates in research, the more likely it is that their involvement helps retention and graduation rates in engineering and STEM fields. Interestingly, they also noted that all students benefit from research experiences, not just students with high GPAs. Therefore, it seems appropriate to start students on the research path early on.

Challenges of Undergraduate Research at a Two-Year College

Incorporating undergraduate research at the community college level presents unique challenges. A two-year college will usually not have a built-in structure for supporting undergraduate research. Particularly in engineering, where expensive laboratories or equipment may be necessary, cost itself can be very prohibitive. The college may not have lab space to dedicate to research, or even have a large enough space to provide for adequate testing of prototypes. Another serious impediment to conducting research can be the lack of an Institutional Review Board (IRB), whose involvement is fundamentally required for any research involving human subjects.

The philosophy of two-year colleges, with its focus on teaching, may also pose its own challenges to the inclusion of research in the curriculum. Talented individuals are often drawn specifically to the community college due to their passion for instruction, as opposed to a drive to produce research. Some faculty members may not have had exposure to research, as not all will hold doctoral degrees and some may have non-thesis master's degrees. This lack of background in formal research may make the idea of incorporating research in the undergraduate classroom considerably more intimidating. Also, faculty members are usually teaching 5-7 classes per semester (as opposed to the 2-3 a year by their four-year counterparts). It can be particularly daunting to add research students on top of this teaching load.

The college will often not have the resources to fund an expensive laboratory or even provide an appropriately-size space for large-scale testing. In addition, in an environment where the emphasis is on instruction, taking on research students in addition to a heavy teaching load can be quite daunting to faculty.

Another threat to research at a community college is the push for courses to be transferrable. Most four-year engineering schools have not institutionalized undergraduate research at all, let alone research at the freshman and sophomore level, so any class in research methods or research experience is highly unlikely to transfer. As the demand for guaranteed transferability increases, faculty wishing to expose their students to research and design must find non-traditional ways to provide those opportunities. For those offering full-semester research-based courses, students must be sold on the idea of the experience has having intrinsic value, since it is unlikely to transfer.

Broadening the Scope of Research

None of these challenges are easily addressed in the traditional model. To overcome these challenges, we must rethink the purpose of research at an undergraduate institution. Rather than focusing on research that is *novel to the field*, the focus instead should be on research that is *novel to the student*. This is a fundamental paradigm shift.

In a model focused on research novel to the field, the faculty member leads research in a particular area, and the student will assist with that research, sometimes receiving a stipend to serve as a research assistant. In a flipped student-driven model, the student approaches the faculty member with a research idea, and the faculty member will assist with that research, occasionally receiving a stipend from the college to serve as a research facilitator.

For example, rather than a student assisting a faculty researcher in analyzing blackbody radiation data (passive role), the faculty member assists the student in designing a radio telescope from the ground up and analyzing the data collected by that student's own instrument (active role).

This unique perspective opens up an entirely new field of options. First, there is no longer a need for faculty members to focus on research. Serving as a research facilitator rather than driving the research itself allows the faculty member to focus on helping the student find resources rather than directing the actual work done. The faculty need not be a subject matter expert in the field; rather, the student is the subject matter expert.

Since research need not be novel to the field, students can scale research to their own abilities. A student with an extensive background in welding can choose a research project that requires those skills. An experienced programmer can choose a design project that requires them to learn complex data structures.

Also of importance is that this model reduces the required financial backing. Engineering projects become more of the tinkering that was more common fifty years ago. Without access to a CNC machine or experienced technician to build to their specifications, students must be resourceful and find other ways to solve a problem. Rather than the lack of financial resources limiting the research, it actually becomes part of the learning process as students become more resourceful.

Implementing Student-Driven Research

In the engineering classroom, research is most accessible at the level of design. It is easy for students to recognize the immediate benefits of design experience to their career goals. There are three ways that we have introduced research and design into the classrooms at our institution: embedded research, independent research, and travel-study courses.

Classroom embedded research is usually the student's first exposure to undergraduate research. Rather than cookbook labs ("Measure 3 g of sodium, stir briskly") or projects ("Create a program to analyze thermocouple data"), where appropriate, labs and projects are refocused to allow students to explore the material in a way that becomes relevant to them.

Independent research on the surface appears to follow more of the traditional model, with the important exception that the research itself is student-driven. Often built from classroom embedded research, a student will take on a more detailed look at a question over (usually) a semester-long research project. The project will culminate with a 30-minute presentation to an appropriate classroom audience as well as a poster presentation. By requiring students to present results in both a presentation and poster format, they are getting experience with those skills that will likely be most relevant to their immediate prospects.

Travel-study courses are one step beyond the independent research. In this option, students not only complete independent research, but do so with a travel component. At McLennan there are two options for travel-based engineering research, with travel to Australia/New Zealand and a humans-to-Mars simulation habitat. An additional opportunity for work in the American Southwest is in development.

Examples of Embedded Research

Certain classes lend themselves more easily to embedded research than others. Our experience has shown that classes that already had labs or projects work better to embed research and design experience than the more lecture-based courses. We currently have student-driven embedded research projects in Engineering Graphics, Engineering Programming, and Dynamics.

Engineering Graphics. This course is usually a first-semester engineering course, where students learn the basics of technical sketching and learn to use solid-modeling software. At the end of the semester, students test for a certification on the software (passing the test is not required to pass the class). The first few years of teaching the class, students had considerable difficulty passing the test. They could do little that wasn't directly out of the book. If they hadn't seen a particular type of example, they hesitated to explore the software, to find new or different ways of doing things.

In our third year of offering the course, we implemented an embedded-research approach to the class which we continue. The first week of class, students are given a deceivingly complex small plastic toy and told to recreate the toy in the software. At this point, the students have absolutely no experience with the software. They have to start clicking around in the software, looking up similar things online. Immediately the tone of the class changes. The students begin hearing over and over, "If I knew how to do it, I wouldn't be asking you." "You're the engineer – you figure it out."

As the class progresses, the projects become more open-ended, until the final project where students are simply told to find a problem with a mechanical solution and solve it. The students then present their designs at the institutional Scholar Day at the end of the semester.

Engineering Programming. This course is a first-semester programming course in MATLAB. In any class, the actual programming experience can range from never having created an assign statement to having a general command of multiple languages. As such, finding an appropriate project always presented a particular challenge for this course. Taking a student-driven approach, we began allowing students to create an interactive game of their own choosing. (In particular, we have the students choose a game because of the required input/output interaction between the users that would not necessarily be achieved by a data-analysis-style project. Also, games seem to bring out more creativity in the students, both in the code and in the final product.)

Whatever the project, students are required to choose something that will be a challenge to them. Students who are experienced programmers are expected to work outside their comfort zone as much as the inexperienced programmer. Students could create their own games, or use traditional standards. Text-based adventure games are popular, as well as trivia games.

Our initial anxiety when implementing this approach was that the experienced programmers would pick something easy that they could complete in a weekend; in fact, the opposite was true. The more experience a student had, the more excited they seemed to get about the open-endedness of the assignment. The top students were pairing up to create a MATLAB version of Monopoly, or creating a Connect Four game with AI that played against the user.

Dynamics. Our Dynamics course is as much of a Capstone course as anything for McLennan Engineering. The embedded project for this class is for students to design a Rube Goldberg machine. Rather than the typical high-school version of this project, potentially involving a lot of dominos and maybe an exploding potato, students must meet specific design goals to demonstrate certain types of motion studied within the class. There are requirements about set-up time and success rate of the machine. (Anyone who has attempted such a machine will recognize the challenge in having a five-minute reset time and an 80% successful completion rate.) Students must build the machines in a CAD program and complete analysis based on that design. Once the machine is built physically, teams then produce full documentation, beginning with the CAD model, then a mathematical analysis of how each step should work, followed by testing, and then a full error analysis. Documentation for these machines usually runs about 50-60 pages, and then the machines themselves are demonstrated at the McLennan College Scholar Day.

Examples of Independent Research and Travel-Study Research

As students see research embedded into their regular classroom activity, they become more open to the idea of completing research on their own. In certain cases, a student's interests will align with a professor's particular specialty, but this is more the exception than the rule. At McLennan, our student research is completed during the spring semester, most often during a student's last semester, although first-year students also participate occasionally.

Full-semester research projects may build upon embedded research projects from the classroom or may be motivated by a student's own particular interests. One student who already held a bachelor's degree in Aviation Science, unable to take the MATLAB programming course due to a scheduling conflict, took on the project of designing a terrain-following terrain-avoidance (TF/TA) algorithm and simulation in MATLAB, with no prior programming experience. Another student took a five-card draw game developed for the embedded research component of Engineering Programming, and spent another semester developing AI that played against the user.

McLennan College has partnered with Tarleton State University to allow the research course to fully-transfer into that partner university's degree plan in Engineering Physics, and many students have completed design projects to meet those goals. One student created a "Simon" memory game from scratch while another built ham radio repeaters.

Pure curiosity has motivated other students. One student designed a graphing calculator app, which in turn required the student to learn Reverse Polish Notation (RPN). Another student, frustrated with the way in which referees were assigned to his soccer club matches, designed an automated scheduling algorithm, motivating a discussion of P vs NP. Both RPN and P vs NP are not usually topics addressed at a freshman or sophomore level, and made both of these projects particularly beneficial to the students.

The travel-study research also provides an additional opportunity for students to engage with their material in an entirely new setting. Our most established travel-based research opportunity is Mars 101. Through a partnership with the Mars Society, McLennan sends small crews of six to Hanksville, Utah, to live for a week in a simulated Mars habitat, living as pioneers may one day live on the Red Planet, rationing food and water, wearing space suits, and living in cramped quarters while attempting to achieve their research goals. Students participating in this experience have conducted research on creating more authentic simulation suits, designing rovers, and developing improved communications equipment.

This year, our institution is offering a new opportunity in the spring semester. Three students will be traveling to Australia and New Zealand to conduct research in engineering economics. One key component of the Engineering Economics course is the use of case studies. With that in mind, the students will be doing a three-part research project. The first part involves researching what case studies are like in this particular field. They need to understand the benefit and importance of using case studies to learn engineering economy tools. The second part consists on finding a topic of interest pertaining to their specific engineering field. For example, an Electrical Engineering student chose to look into the economic aspects of geothermal energy versus hydroelectric energy in New Zealand, a highly debated topic. Next, the student needs to find a case study to solve. In the case of the aforementioned student, he will take the point of view of an environmental agency making a case for geothermal energy, informing decision-makers such as companies and individuals whether they should add more geothermal energy to their alternative energy mix. The student needs to research and find relevant financial data to be later used in the analysis. The third part of the research project is to use engineering economy tools to provide recommendations based on the results of the analysis. During the trip, the student will visit a geothermal facility and speak with several experts about geothermal energy, hoping to find additional useful information for his case study.

Benefits of Student-Driven Research

Exposure to student-driven research and design has already had a strongly positive impact on both the individual students involved and on the institution as a whole. We have also had a surprisingly positive reaction from our Engineering Advisory Council, made up of local employers. They are particularly pleased with the emphasis on hands-on design and technical presentations, and are beginning to ask to be more involved, with mock Product Design Reviews and similar activities.

One often-ignored, but fundamental, distinction of a research-based approach to projects is that students will begin a project without a guarantee of a solution. In an age of well-circulated solutions manuals and online homework websites, well-designed research and design projects have no easy answer. This in particular has been well-received by our Engineering Advisory Council, because such activities demand the students develop the problem-solving skills they will need in the workplace. There is no guaranteed approach for results. Students must try, fail, and reevaluate their approach in a real context.

From an employers' perspective, students are gaining early experience in managing complex projects, something their four-year counterparts will not usually see until a senior design class. They learn the importance of ordering parts early, of how to write a request for funding, and what to do when everything seems to go wrong

But it is indeed the relevancy and student-driven aspect of the research and design that keeps students working on the project long past when they have met the learning objectives. One student in the MATLAB course created a program for his daughter to practice her math facts, complete with audio files of family members providing encouragement, far beyond the basic requirements of the assignment. In a team environment, this becomes even more obvious.

One particular benefit of research and design in teams at a community college is that often students come from very non-traditional backgrounds. Teams may consist of a recent high school graduate, a recently discharged veteran, someone who runs his or her own machine shop, and a liberal arts major coming back to college for a second degree. This wide array of backgrounds provide for an incredible learning opportunity for each member to contribute in a unique and meaningful way. Since the students are designing their own work, there is incentive for them to teach each other. The student with the B.A. in Music learns to use a weld torch, and the former military aircraft technician sets the student with great writing skills but little hands-on experience straight about using slot- or Phillips-head instead of “minus sign” and “plus sign” screwdrivers.

The literature is full of case studies showing that exposure to research is good for students at any level. Student-driven research provides an even greater benefit, by showing that the student is capable of creating quality work. We have seen students who initially approach the idea of research as, “That’s not for people like me – that’s for the smart people,” and as they find their niche in a group, or explore concepts on their own, move out of that trench and begin to recognize in themselves someone who can lead on a concept. Since the work is student-driven, the student becomes the subject matter expert. This builds an enormous amount of confidence and enthusiasm. Students short on practical skill but high on passion can be encouraged and motivated through these projects.

We also have noticed the retention effect of undergraduate research on our own students. So far, all students who participated in undergraduate research are either still enrolled in an engineering program, or have graduated. One has already moved into a doctoral program in engineering.

Future Opportunities

We are very encouraged by initial results. Students respond well to having more control over the direction of their work. Interestingly enough, however, students brought up in this culture seem to have difficulty recognizing that their experience would be any different at another institution. We have noticed in particular that students need training on how to capture their research and design experience into their professional resumes, and on how to discuss these experiences in a job interview. We are currently looking for better ways to capture lessons learned from one set of students to the next. Although we have considered having more long-term projects, we have serious concerns that this will drive us away from the student-driven approach.

Funding continues to be a challenge, though our institution has formed a committee with a small budget to help fund both the research projects themselves as well as travel to conferences to present such projects. A few of our students have been successfully placed in REUs, based on their research experience, but we need to push these opportunities more diligently for our students. As we continue this program, we hope to collect more firm data that supports the anecdotal evidence that we have gathered thus far about benefits to our students and how the work will ultimately support their success in future career plans. Whether through open-ended design projects, embedded research, or full-semester research endeavors, students come away from the experience with an enriched background that will ultimately serve them well as they continue on to their transfer institution and on to graduate school.

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