A Study on Undergraduate Engineering Research

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***Abstract*—This research-to-practice category full paper describes the benefits of undergraduate research and through online research demonstrates the methods used by the higher education institutions to introduce their students to research. We conducted at the home institution a survey of students not previously involved in research and found that most engineering students (88%) are interested in undertaking research. 83% of students would like to engage in both laboratory and computational work for their research. The research topics of most interest to students in descending order are sustainability aerospace applications, energy, materials, infrastructure, and robotics. Students believe that the most significant benefit from research is developing skills other than those taught in their classes (i.e., creativity, diligence) and that the major barrier to not performing research is either not having time or not knowing how to start. Students would be mostly interested in research if the research project is of interest to them and they are less eager to publish and present their research results at engineering conferences and other venues. 61% of students wish to collaborate with other students on research projects under the guidance of a faculty member.**

To increase the first-year students' interest in research and develop an entrepreneurial mindset, the paper presents a project that can be incorporated in the Introduction to Engineering course. First-year students are asked to develop and answer their own research questions and learn how to pursue patents for their discoveries. Such projects can help students understand what research is and make them start working on faculty mentored research projects as soon as their first year.

Keywords—undergraduate, research, first-year, engineering, survey, project.

I. Introduction

Undergraduate research is part of the experiential learning activities such as hands-on laboratory experiments, internships, practicums, field experiences, and studies abroad that greatly benefit students and help them attain real world engineering experience while they are still pursuing their degree. Merriam-Webster dictionary defines research as the investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws [1].

Benefits of research are well cited in literature and include encouraging critical thinking, personal growth, and intellectual curiosity. Students and faculty members involved in undergraduate research, report that the most beneficial result for both was students' developing further their problem-solving skills [2]. Research courses offered by universities prepare students better for graduate studies [3]. Faculty-mentored research has shown to improve students' communication skills, and has increased the student self-identification as engineers.

Undergraduate research can be course-based (pedagogical) or faculty mentored research where students work under the guidance of a faculty member one-on-one or in small groups. Other opportunities for research exist through the research experiences for undergraduate students sponsored by the National Science Foundation (NSF), professional societies, national laboratories, and federal agencies. Undergraduate institutions often offer Honors programs for academically advanced students and undergraduate research courses. In all cases, universities employ research for retaining and producing highly qualified graduates to work in industry or to pursue further graduate studies. Research students, including underrepresented student populations, tend to attend graduate school and they increase the university's retention rates [4, 5]. In other cases, research is combined with trips abroad, where selected and often from minority groups students participate in summer research activities [6, 7].

It becomes evident from the above discussion that not all engineering students can participate in undergraduate research due to lack of such programs in their institutions, not having sponsored research and having fewer research active faculty. The percentage of participating students ranged from 2% to 3% [8] in earlier years and it is now reaching about 40% of the students at large research universities. Research courses are also attended by only a few students with good academic standing. There is, moreover, competition from higher achieving students for limited positions and other personal obligations distracting students from focusing on research [9]. Course-based research, on the other hand, allows the participation of all students and overcomes the barriers mentioned above.

II. Research Question

Given the benefits of research on student learning, retention, and success with continuing their studies for advanced degrees, we aim to answer the question of how we can increase the

interest of students in research as early on as in their freshman year and how we can increase the number of students that overall participate in research projects.

III. Methodology

We utilize online research and an in-house survey to examine how universities involve undergraduate students in research and what makes students interested in participating in research projects. Given our findings, we propose a project that can be incorporated in the first-year introductory engineering courses that can expose all freshman students to research and entrepreneurial mindset. This first-year project will enable participants to make informed decisions on pursuing research during their consequent years as students or even later in their professional lives.

A. Online Research

We did an online search of 100 universities offering engineering degrees to find out if and how they engage their students in research. These universities represent all states with more universities being in Texas, California, Florida, Ohio, and New York. We investigated if the universities employ their undergraduate students in research and if they are organizing research conferences and symposia. We also examined if the students could publish their work in university-led peer-reviewed journals.

Although students have opportunities to publish their work, for example the Council on Undergraduate Research allows for students to publish their work on the academic journal "Scholarship and Practice of Undergraduate Research," 60% of the institutions have a journal for engineering students to publish their work resulting from undergraduate research mentoring. Several of these journals also publish reviews for ongoing research projects at these institutions as well as interviews with research professors detailing the advances of their recent research projects. Such research journals allow undergraduate students to learn about and gain hands-on experience with the peer review.

91% of the universities provide online instructions to undergraduate students on how to approach and request research mentoring experience from experienced faculty members. The faculty members' research, their projects, and theoretical background are well advertised, too. The universities also provide information on how to apply for fellowships, scholarships, as well as research experiences with national labs, federal agencies, and the private sector. R1 universities often have collaborations with agencies such as NASA dedicated just to their students.

Several of the universities have Honors programs for highly performing students and others offer some type of course dedicated to research. 87% of the universities organize symposia and conferences where undergraduate students can present their work and practice their communications skills.

B. Survey

The student survey included 14 questions and a sample of 41 undergraduate students who have not been involved in research before. Figs. 1 and 2 show that most interviewed students are freshmen with a major in mechanical, computer, and civil engineering. Introductory survey questions addressed why students become engineers, and if they know what research is. Fig. 3 shows that the major driver for studying and becoming an engineer is helping the society followed by the financial success. The number of students that are still unsure about their choice to become engineers during their freshman year is very small. These results are in accordance with those from previous studies performed at different institutions [10]. Figs. 4 and 5 illustrate that 95% of students understand what research is, 44% definitely would be interested in performing research and 51% of them most likely would be involved in research..

Fig. 6 shows reasons why students may select to undertake research. Most students would perform research to develop other skills than those needed in class (i.e., creativity, attention to detail), followed by understanding how knowledge is constructed, and developing self-confidence. The least beneficial aspect for research is learning to work independently. When students were asked what the major barrier for not doing research is, they responded not having enough time and not knowing how to start, followed by receiving compensation, and combining research with travel to another institution, Fig. 7. Moreover, Fig 8 demonstrates that only a small amount of students majoring in engineering would be motivated by publishing and/or presenting their research at conferences. The main reason why students would select to participate in research activities is working on projects of interest to them

61% of students would prefer to work in a team and 32% to work one-on-one with a professor, while the remaining 7% cannot distinguish between the two and would equally work in a team or on an independent research project with a faculty advisor. 83% of students would like to engage in both laboratory and computational work for their research. When students were asked if they would like to have research incorporated in a course only 20% reported that they wish that while the remaining students would either not see any benefit in course-based research or they were not sure about it.

Table 1 gives a list of research topics from which students were asked to select and shows their preference for a research topic. Sustainability came first in their preference showing that students are interested in helping society by meeting the needs of the present without compromising the natural resources for future generations.

TABLE I. RESEARCH TOPICS

Research topic	**# of Students**
Sustainability	20
Aerospace Applications	12
Energy	11
Materials	9

Research topic	# of Students
Infrastructure	8
AI/Robotics	3

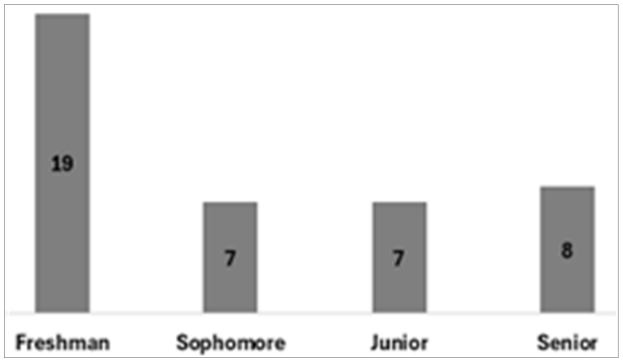

Fig. 1. Classification of students.

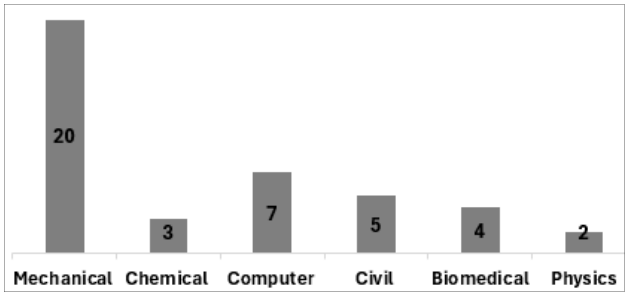

Fig. 2. Majors of survey participants.

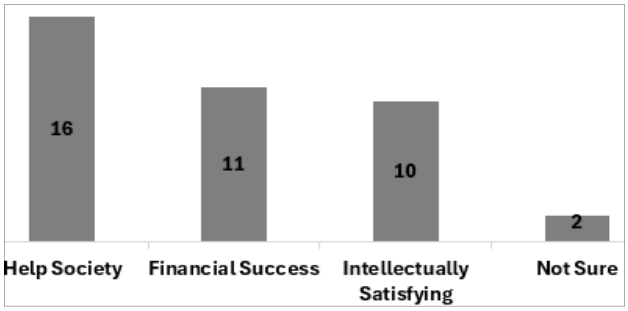

Fig. 3. Why did you choose to become engineer?

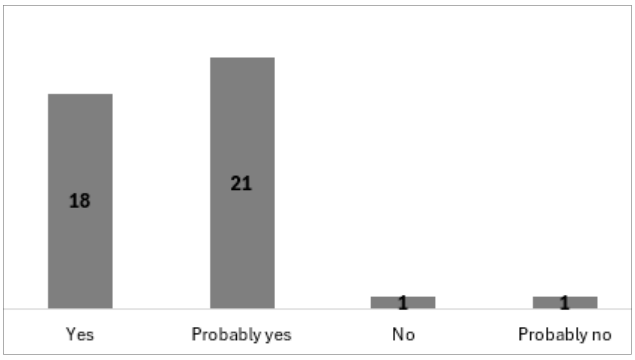

Fig. 4. Do you understand what is research?

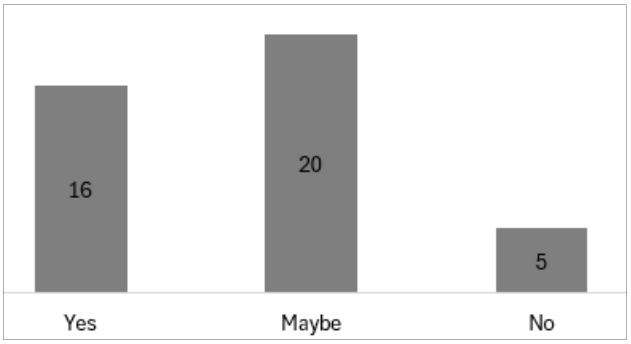

Fig. 5. Are you interested in research?

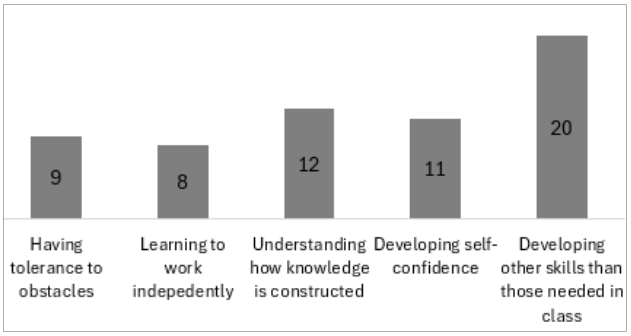

Fig. 6. What is the major expected benefit about doing research?

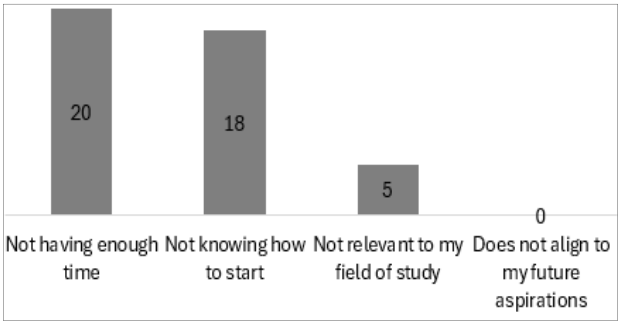

Fig. 7. What is the major barrier for not doing research

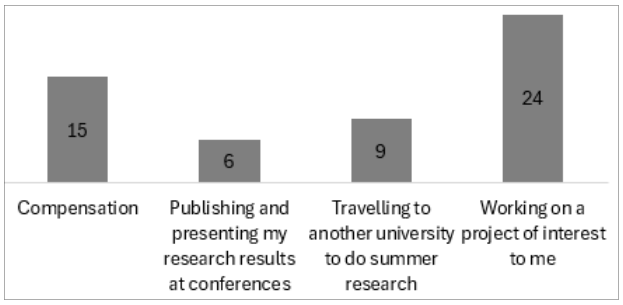

Fig. 8. What would make you interested in research?

IV. Discussion

From the previous sections it becomes evident that only a small percentage of students gets introduced to research after having to actively look for the opportunity themselves. The survey showed that even interested in research students do not know how to start pursuing research. The research students selection process is very competitive and sometimes is only limited to the Honors students, for faculty mentored research at their home institution or through national labs and federal agencies or even through the private sector. Oftentimes research courses are available for students. However, these courses may increase the financial burden on students or limit their choices for major related elective courses.

The benefits of research are significant. Students recognize among others that research can help them learn how knowledge is constructed, develop self-confidence, and develop skills not being taught in class such as attention to detail. Therefore, we propose to introduce research to all students during their first year of studies. Studies showed that introducing research in the freshman year helps the retention of students, and increases the pride in both the department and the university. Moreover, the students' performance improved in the subsequent years of studies [11].

In what follows we describe how the first year engineering design project can be modified to include research activities that can reinforce moreover the students' entrepreneurial mindset. We then explain the methods of assessment and the benefits of such an endeavor.

A. Introduce Research during the Freshman Year

Previous studies [10] showed that of 182 examined institutions, 11% do not offer an introduction to engineering course, 30% offer a discipline specific course and 59% an interdisciplinary course with students from all engineering majors. Of interest to this study are the institutions offering an interdisciplinary introduction to engineering course. In such a course, students get exposed to several engineering topics that relate to the ABET Criterion 3 student outcomes [12]. According to [10] such topics include and are not limited to graphical presentation, technical writing, oral presentation, professional organizations, overview of engineering disciplines, ethical and professional behavior, hands-on learning and experiments. Moreover, students learn the design process and get to work on simple design projects [12]. The instructors provide usually students with the projects' specification that they must follow to meet their clients' needs. Some project examples include Knex cars, truss bridges, cardboard chairs, simple machines and mechanisms, water purification systems, medical and electronic devices, [13], etc.

To broaden participation in research, we propose for all first-year students to act as researchers and define the scope of their design problem or else set the research question. Students will still get the same exposure to engineering topics with only difference their design project being defined by them. The students then need to find an engineering solution to the proposed, usually societal engineering problem of their choice, with the requirement to develop a new idea or to expand and add a new component to an existing engineering solution for the problem under consideration. This assignment complies well with the definition of research [1]. Moreover, the students need to work in teams. This supports the preference of students to work in groups while performing research.

The steps for the realization of the proposed design project requires students to:

- create teams after a class meeting where they get to discuss their interests with fellow classmates. This will allow students not to lose their motivation and work on projects of personal interest [14]. Moreover, this helps students decide about the major they will pursue by selecting to solve problems in their preferred engineering area.
- attend a presentation about the research resources available to students at their home institutions, for example library and available database resources.
- define the problem, which in most cases addresses a contemporary need of the society (i.e., improving flooding conditions, creating devices to help people with disabilities, help restore the environment, increase sustainability, generate green energy, etc.).
- specify how their proposed solution is innovative to a degree and has not been proposed by other researchers and/or designers.
- prepare a first draft of their design report and orally discuss their proposed project with the instructor. This is the time that the students have to clearly differentiate between research and application of an existing solution to the problem under consideration. The role of the instructor is crucial as well. After such a discussion the students may need to modify the proposed solution and perform more research on the topic or select to propose another problem that can be addressed with an innovative solution.
- follow the design process [15] to realize their solution and critically formulate results and conclusions.
- prepare a final report and an oral presentation with the research findings to the student community.
- select along with their classmates and the instructor a winning project with the more innovative problem definition and solution.

It is recognized that due to time limitations the projects might not be well developed by the end of the course. Such a difficulty may be overcome by forming four- student teams, so that more work could be done in the prescribed time. The assessment of the student work should rely on the resourcefulness of students and the originality of the selected project along with other criteria necessary for design projects such as team work, oral and written skills.

A useful addition to the introduction to engineering course could be an introduction on patents, how one can write and pursue patents [16]. Such an addition to the course can further energize and excite the students minds, who can start seeing themselves as entrepreneurs.

B. Anticipated Benefits

By incorporating such a research assignment in the introduction to engineering course we believe that the following benefits can be achieved for students:

- Overcome difficulties such as limitations in faculty research mentors availability and expose all students early on to research.
- A course-based research requires less time commitment by students, as undergraduate students have less available time than the graduate students.
- Strongly interested students in engineering research will pursue their interest more intensively while at the university or later as professionals.
- Freshman students get more interested in engineering and retention rates can increase.
- Young engineering students learn how to apply for a patent for their innovative work. All students get awareness about technical innovation how to pursue it and benefit from that over the long run.
- No advanced mathematics are required for such research projects because students identify the needs of knowledge and not necessarily solve the problem completely.

Additionally, to student benefits, the instructors teaching the course will benefit, too. They will need to stay current in multiple engineering fields and use their own resourcefulness to help students innovate. Moreover, senior research faculty could lead the introduction of engineering course or serve as consultants for the student defined research projects.

C. Implementation and Future Work

A sample of approximately sixty interdisciplinary engineering technology students at a public university were given this project assignment for their introduction to engineering course by the same instructor. Student teams of three met with the instructor during office hours to determine the originality of their project as described previously. About 20% of projects were rejected due to lack of originality and students were given feedback on how to find a more innovative approach to the identified problems. The projects that the students selected addressed issues related to difficulties in their everyday life and to helping society at large. For example, flooded roads, potholes, bridges and tunnels to shorten their everyday commute, devices to help people with disabilities and equipment to help the military missions abroad were just a few of the addressed problems.

This was just the initial implementation of the project. The instructor clearly saw the excitement of the students when defining their problems and judging the resourcefulness of other engineering teams during the final project presentations in class. In the course evaluation, participating students mentioned that their interest in pursuing engineering has increased. The instructor, moreover, got encouraged and fascinated by the resourcefulness of future engineers.

Future work will need to implement the project in different sections of an introduction to engineering course. Having a control group and comparing it with course sections where the project is implemented will allow to longitudinally study the impact of this project on retention, recruitment, and student success.

V. Conclusions

Undergraduate research is beneficial for undergraduate students because it provides them pride and the ability to gain skills that are not necessarily taught in class. Online search showed that the majority of the universities offer faculty mentored research to their students who have the ability to present their work at research symposiums hosted at their home institutions. Several universities also have journals for students to present a paper version of their research. Universities provide students with instructions on how to pursue researching by contacting faculty members. However, the selection process is very strict allowing in most cases only highly performing students to get such opportunities with a faculty member as a mentor or at national labs and federal agencies.

Our survey showed that students know what research is and would like to pursue it, but they do not how. Therefore, we propose a project to be incorporated in an interdisciplinary Introduction to Engineering course, where all the students will have the opportunity to get exposed to research, learn to define research questions, pursue innovative solutions and learn how to file patents for their potential discoveries.

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