Undergraduate Research -What is it?

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Abstract

Undergraduate research is now widely seen as one of the major paradigms for engaging students. In the US, undergraduate research opportunities have become a common expectation of almost all incoming students and their parents.

By bringing together the experiences gathered by a large number of colleagues at leading undergraduate institutions, I will describe the general understanding of undergraduate research. At Loyola University Chicago, for the last sixteen years, we have been engaging students in research from the very beginning of their careers. I will discuss this innovative Freshman Research Program, which has become a segue for many to more advanced undergraduate research at Loyola, and is making a profound impact on our program.

1. Introduction

At the 2003 meeting of American Association of Physics Teachers (AAPT), Steven Weinberg stated that when he graduated from Cornell, he was a good student, but not a good physicist. As he explained later, he meant that he had no idea how one carried out research without first knowing all that was known in the field of physics.

This is a very telling statement. It clearly shows the need for introducing elements of research into our undergraduate curriculum. Incorporating research would not only prepare them well for graduate education, but would also help students engage with a faculty member, and focus deeply on a particular project, and critically analyze various facets of the problem.

Undergraduate research (UG) has become a vehicle for deeper, more engaged learning. With the sense that education is becoming increasingly expensive, it has also become an expectation of parents that students will receive opportunities for research and internship during their undergraduate education at private or public universities. As a result, many universities now explicitly advertise the various ways in which they would engage incoming students during their formative years. According to Guterman [Guterman-2007], "The National Science Foundation spends some $50-million yearly to support about, 500 students just in its largest undergraduate research program, the summer Research Experiences for Undergraduates. The Howard Hughes Medical Institute supports an additional 3,300 students. Over all, some 40 percent of students majoring in the life sciences and physical sciences do research with a faculty member, according to

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two surveys: the National Survey of Student Engagement, which canvassed more than 65,000 students at 209 colleges and universities, and a study performed by the Reinvention Center, at the University of Miami, which surveyed administrators at 75 research universities to get estimates."

To some extent, this pressure to introduce research at the undergraduate level had left many of us somewhat bewildered. Even today, there is still quite a bit of confusion as to what exactly constitutes undergraduate research. In Sec. 2, I will describe some of the common understanding of undergraduate research, much of it is based on our experience at Loyola University and from talks given by several authors at various conferences [Dawkins-2010, Gentile-2007, Hilborn-2001, Sudhakaran-2009].

In Sec. 3, we describe the undergraduate research program at Loyola University Chicago. In the physics department at Loyola, we now have a highly developed structure for involving students through project-based learning. We started our program well before the current trend, and have been continuing it for the last sixteen years. We require that all our students participate in at least a one-semester-long undergraduate research experience beginning no later than the second semester of the freshman year. These are called freshman projects. Many students continue this research beyond their freshman year.

In appendix A, I list some of the recent projects of our students. In appendix B, to provide an explicit example of how freshmen projects develop into more advanced research topics, I have attached a poster from a conference attended by two of our students. It shows the maturation of their research through the four years of their undergraduate education at Loyola. In appendix C, I have attached a brief description of a national study of the impact of undergraduate research on students at predominantly undergraduate universities [Guterman-2007, Hilborn-2003].

As is well known, these are very time consuming endeavors. Most universities do not yet have a mechanism to give the appropriate credit to students and faculty members for their tremendous work in running these projects. It is crucial that upper administration supports such ventures. Without full support from the administration, it is almost impossible to find sufficient resources for research, and to provide the necessary teaching reduction for faculty members that that are fiercely active in mentoring students. I will describe some of the steps we have taken to incentivize these projects, and to allocate proper credit to students, as well as their advisers.

2. What Counts as Undergraduate Research?

Until very recently, the general perception was that undergraduate students were not capable of doing research. However, from the numerous conferences on this subject, it is becoming clear that the concept of UG research is taking Hold.

According to Dr. Nancy Hensel, the former executive officer of the Council of Undergraduate Research (CUR), the council has about 7000 members. CUR have put together a 72 -page long monograph describing "Characteristics of Excellence in Undergraduate Research" [Hensel-2012]. "It is based on the collective experience, over many years, of CUR members who have engaged undergraduate students in research, developed undergraduate research programs, mentored new faculty to include undergraduate research in their teaching repertoire, and coached universities in the development of undergraduate research programs⋯ .The instrument aspires to present the best practices in undergraduate research. It can be used as a guide for institutions that are striving to enhance the learning experiences of students through research program." The monograph succinctly describes undergraduate research at many schools in various disciplines. It can be a great resource for schools/departments that are in the process of initiating an undergraduate research program.

While the meaning of research varies among disciplines, there are several concepts that are common to all programs. Here we describe some of the basic ideas that describe UG research, as we see them. [2]

2.1 Define and promote research broadly

The word "Research" has to be understood in a rather broad sense. The process must have discovery associated with it. It could be as simple as a student (or a group of students) discovering various parameters that affect frictional force between two surfaces, or it could be a collaboration with a researcher in a big project publishable in a big named journal. Sometimes, at least in the initial stages, UG research may be not very different from glorified independent reading, or special lab projects.

To insure that student does not lose confidence in his/her learning, it is advisable to start small and build slowly. The level of research should grow with the student. In appendix A, we give a list of projects that our beginning students worked on during the last two academic years. The appendix B shows a particular project that turned into a research project which was presented at several professional meetings and is expected to lead to several publications.

2.2 Build Student Research into the Curriculum

If possible, require research as part of the curriculum. It can be done by embedding research projects into the courses for majors. In some schools, there is a thesis requirement that students must fulfill in order to get their undergraduate degrees in physics. For programs that require a thesis, it could be the culmination of research done over the undergraduate years. Many schools demand a capstone experience for their students, which could be a good place to introduce elements of research in case students haven't had a chance to experience research earlier [3].

While students should be encouraged to participate a long-time research projects, it is pedagogically more effective to scatter small research projects throughout the curriculum, and thus help build their research skills. This type of intentional incorporation of research opportunities will insure that a larger number of students get exposure to research methods. Since our textbooks are generally not designed for such open-ended project based learning, such modifications are generally very time consuming endeavors for faculty members.

2.3 Mentors Must Challenge Students and Empower them to Succeed

It is very important that faculty members make clear to their advisees what the expectations from the project(s) are. S/he should also make the student aware of the challenges, especially the possibility of not getting a publishable/presentable result.

The faculty member would need to keep in mind that building confidence in student must remain one of the main objectives. Even if a project does not generate exciting results, s/he will need to emphasize the skills that were picked up in the process and would be helpful to them later.

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[2] We will mainly limit our discussions to physics related projects.

[3] Since capstone courses are generally taken during the senior year, we prefer that research experience begin much earlier in their career.

2.4 UG Research Must be Visible

One of the important aspects of undergraduate research is that it must be visible [Hilborn-2001]. By visibility, we mean that work must be disseminated via all possible avenues. Within the university, there should be research presentation days. Local chapters of the AAPT are good places for presenting undergraduate research. In bigger cities, there are local Undergrad Research Symposia for such presentations. Depending on the level of research, manuscripts should be prepared for undergraduate research journals, and if warranted, for well known peer-reviewed journals. We owe it to our students that their research be made available to the wider community.

3. Undergraduate Research at the Freshman Level

In this section, I will describe an innovative Freshman Research Projects program that we initiated at Loyola. All of our physics majors must have research experience through their first year experience in the department. We will describe how our projects got started, what their current objectives are and how they have affected our program.

3.1 Genesis

We started this innovative program in 1996. It was originally developed to engage students in deeper learning through research starting from their freshman year. But as we will describe below, it has helped us achieve many more goals. We have continued these projects, without break, for the last sixteen years. In 2005, our projects were featured in an article in the Chicago Tribune [Kapos-2005]. In 2009, we elevated this program to a required course so that students, as well as advisers, would get credit for their enormous time commitment.

3.2 Goals

These projects serve several goals.

a) First, they allow students to explore a single problem more deeply than is generally possible through a regular lecture-based course by engaging in research.
b) Second, students working in small groups develop closer relationship with other physics majors. As our majors work together and get to know their advisers, it also instills a sense of community among them. Under the watchful eyes of their mentors, students learn to work as a team.
c) Third, students, in collaboration with their faculty advisors, choose viable topics that match their interests and can be accomplished within a given budget. The project must have a thesis, must have a building component, a theoretical infrastructure, data collection, analysis of the data, and must have a presentation in a departmental symposium. Thus, with the freedom to design their own projects, responsibility of insuring that the project conforms to the constraints given, they are taking charge of their own education, and are encouraged to think creatively.
d) Fourth, the relationship they form with their adviser helps many students to go into more advanced research in later years.
e) Finally, these projects offer our students experience in oral and written presentations, and introduce them at an early stage of their scientific careers to the realities and excitement of exploring physics. In many cases these projects blossom into publishable[4] research by the time they are juniors and seniors, and many of them present their work at local and national meetings of the relevant professional societies.

[4] Sometimes published in peer reviewed journals, and often presented at undergraduate research symposia and professional meetings.

3.3 Description of the Freshman Project

3.3.1 Objective

The objective of the Freshman Projects course (PHYS 126F) is for students to develop and carry out research on a project that uses concepts covered in the introductory physics course for our majors, but that goes beyond the work done in a standard classroom. Potential physics majors in the introductory physics course (PHYS 126) are divided up into ten small groups with a maximum of 5 students per group. Students in each group choose a faculty adviser. Each group must submit a proposal outlining the goals of the investigation. They are required to keep a scientific notebook and document their work throughout the semester. Each group must design an experiment for the investigation, use our machine shop to build the necessary apparatus, develop theoretical infrastructure, carefully carry out the experiment, collect data, and carry out a systematic analysis to see whether their finding supports or refutes their thesis. Students are required to spend a minimum of 42 hours on these projects, but they generally invest many more than that. At the end of the semester, students create a poster and give an oral presentation at a specially arranged seminar that is attended by all faculty members and a large number of advanced students. In appendix A, a list of the projects from 2011 has been attached.

Some freshman projects have been presented at local and national meetings of the AAPT and undergraduate research conferences (specifically the Chicago Area Undergraduate Research Symposium and the Argonne Symposium for Undergraduates in Science, Engineering, and Mathematics). We believe that positive experiences with the Freshman Project encourage students to pursue undergraduate research opportunities beyond their freshman year.

In addition to giving freshmen very valuable research experience, the Freshman Project serves other pedagogical and social goals within the department. In one marvelous case, an advanced student took 15 freshmen under his wing and led them in a research project of his own. In a department with a relatively large undergraduate population, it may be difficult for students to become acquainted with the department faculty, especially before they have taken (generally smaller) upper-level classes. The Freshman Project provides opportunities for students to work closely with a faculty member early in their careers as students, and to become more acquainted with the department beyond their professors teaching introductory physics lectures and lab. It helps students develop collaborative learning skills. Additionally, working in small groups helps students to meet each other and to develop a sense of identity as a group of future scientists.

One way in which our program differs from many other undergraduate research opportunities is that the Freshman Project takes place in a student's first year, as opposed to traditional undergraduate research and Research Experience for Undergraduate (REU) programs which frequently target students later in their career, often at the junior and senior level. As mentioned above, research performed during a students earliest years is essential [Hilborn-2003].

Thus, we believe that the Freshman Project program has indeed brought students together with a sense of a scientific community, offered them experience in oral and written presentations, and introduced them at an early stage of their scientific careers to the realities and excitement of exploring physics outside of the textbook.

3.3.2 Integrating Technology

Another important goal of our freshman projects is to familiarize students with the technologies that scientists use to perform research and communicate scientific results. Developing an early fluency with these tools encourages their use throughout the students' undergraduate careers and adds valuable skills to their repertoire as they prepare to enter the workforce or pursue graduate studies.

Students are encouraged to investigate their projects using software packages that practicing researchers use. To this end, the students use software like Mathematica, a general-purpose system for technical computing, or LabView, a simulation and data gathering environment.

3.3.3 Assessment

Students are evaluated based on the quality of the projects and presentations, as well as on their collaborative participation in the design and implementation of their plans.

3.3.4 Effect of the Freshman Projects on the Physics Program

As stated in the beginning, the Freshman Project experience at Loyola University Chicago began during the 1995-1996 academic year. From the very beginning, the main motivation was to provide an additional framework to get students engaged in deeper learning. At the time the Freshman Project was introduced, the LUC Physics Department was struggling to attract and retain students. In the mid-1990s, many physics departments experienced low enrollment, and Loyola was no exception [Hilborn-2003]. For the five years prior to the introduction of the Freshman Project (1991-1995), the LUC Physics Department graduated 24 students total, for an average of 4.8 per year.[5]

Since the inception of the Freshman Project, the Loyola University Physics Department has experienced very strong growth. According to the American Institute of Physics (AIP), LUC was tied for the eighth largest average graduating class in the nation during the period 2005-2007 and fourth during 2006-2008, among bachelors-only departments, with an annual average of 17 and 22 graduating students respectively [AIP Statistics Tables-2012].

3.3.5 Bridge to Advanced Research

Many of these freshmen go on to carry out further research during their sophomore, junior and senior years. In appendix B, we have described the work by Benjamin Irvine and Matthew Kemnetz that began during their freshman year in 2009. They have presented their work at various fora including two different national meetings of the AAPT. A manuscript describing their work is available at the physics archive [Irvine-2012]. There are others students that have published papers in prestigious journals such as Physical Review E with my colleagues at Loyola.

Our experience shows[6] that students that go into research beyond their freshman year, generally go to graduate schools in physics or a related field after leaving Loyola.

3.3.6 Involvement of the Administration

As stated earlier, it is essential that faculty and administration both see undergraduate research as an important paradigm for engaged learning. Fortunately for us, the vision of our upper administration for the university - a place for an excellent undergraduate education - fits very well with our vision for a vibrant department with a strong culture of research with undergraduates. The administration has made available resources for several modest projects running simultaneously. It is specially noteworthy that through the Office of Experiential Learning, Loyola University provides a large number of scholarships to students engaged in undergraduate research. We have a special annual

[5] It is important to note that 4.8 graduate/year was about double of the national average. We are currently about five times the national average.

[6] This is contrary to the observation of Ref. [Guterman-2007].

symposium for presenting undergraduate research. Every April, a large number of undergraduates from many disciplines present posters describing their research. Such efforts are essential for a culture of undergraduate research to emerge on a campus-wide scale.

3.3.7 Compensation for Faculty

Many of our members spend a substantial part of their week with students guiding them in Freshman level research and beyond. During summers, when teaching loads are comparatively low, mentors spend an extraordinary amount of time in mentoring students. These faculty members cannot be adequately compensated for their noble effort, at least not monetarily. We have now elevated the freshman research projects into a course. Thus, students taking part in these projects receive academic credit, and faculty members get credit for mentoring. We also have courses designated as "Undergraduate Research", and advanced students can take these courses for up to a total of 12 credits. Mentors receive teaching credits if students register for research courses under their supervision. Involvement with undergraduates, especially research with advanced students, is taken very seriously in annual evaluations, and in promotion and tenure.

4. Conclusion

Undergraduate research is widely seen as one of the major paradigms for mentoring our undergraduate students [Guterman-2007, Gentile-2007]. In our attempts to provide a transformative educational experience for our students, we have identified undergraduate research to be one of the best ways to engage our physics majors. These projects not only bring research experience to our students very early in their career, and thus engage them in deeper learning, they also serve as gateways to more advanced research beyond their undergraduate education.

5. Acknowledgement

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Appendix A. Freshman Projects

Spring 2011

1. *Parametric Resonance:* A. N. Nguyen, C. Banaszak, O Salman, C. Staszel, A. Curcuru; **Prof. John J. Dykla**

   There is a coupling between verticle spring harmonic and angular simple harmonic motion. The purpose of our project was to study and create equations for this phenomenon using controlled experiments.

2. *Analysis of Pianos:* S. Adhikari, C. Choi, K. Filip, M. Guzman, and T. Jozefczyk; **Prof. Gordon Ramsey**

   The purpose of our project is to understand how string vibrational and acoustical properties differ in grand and upright pianos. ⋯

3. *Optical Response to Changing Water Droplet Shape:* A. Bayrak, J. Minalt, N. Kuehnle, F. Uddin; **Prof. Robert Polak**

   Use of water droplets to focus light into solar cells requires a consistent focal length. ⋯

4. *Behavior of a Loaded String:* K. Kadowaki, T. Massutti, A. Michael, J. Ong; **Prof. Robert McNees**

   This experiment studies the behavior of standing waves on a loaded ⋯

5. *Introduction to Aerodynamics:* The Effect of Shape, Size and Texture on a Falling Object's Acceleration A. Jagadeesan, G. Pfaff, N. Pflederer, J. Thompson, **Prof. Dr. M. K. Udo**

   We are interested in learning the effect of air drag on objects as they undergo free fall. ⋯

6. *Preliminary Investigation of Wind Turbines and Solar Cells:* A. Kepler, S. Kim, I. Kusmic, W. McDonald, E. Varty; **Prof. Thomas Ruubel**

   We were interested in sustainable energy generation. ⋯

7. *Dry Friction Tribology: Science or Art?* W. Ascenzo, C. Choo-Kang, P. Patel, and B. Payan; **Prof. Aleksandr Goltsiker**

   Several centuries after the first insights of Leonardo da Vinci regarding the behavior of sliding blocks, Amonton reported his experimental results on the dry friction force, which he found to be both independent of interaction and contact area and proportional to normal force, in the late 17th century ⋯

8. *Study of Large Amplitude Oscillations:* F. Giurgiu, C. Mcginty, J. Ross, **Prof. Asim Gangopadhyaya**

   ⋯ We also designed and studied a physical pendulum using a bicycle wheel with a mass attached to the inner rim of the wheel. We compared our observations with numerically obtained results.

Spring 2012

1. *Physics of Rubens Tube:* Alex Acosta, Gabriel Fuentes, Grace McClusky, Kirril Lavrenyuk and Ken Johnson; **Prof. John Dykla**

2. *Study of Viscosity: Newtonian vs. Non-Newtonian Fluids:* Tyler Bobella, Sarah McDowell, Joseph Sawicki, Derek Thayer; **Prof. Jonathan Bougie**

3. *Electromagnetic Accelerator:* Joseph Cecala, Aidan Klug, Luis Ortega and Andrey Puzanov; **Prof. Asim Gangopadhyaya**

4. *Wave-Powered Generator:* Robert Medina, Mark Peterson, Farheen Syeda, Dan Zimmerman; **Prof. John Cunningham**

5. *The Physics of Banjos*: Joseph Bella, Alex Gilman, Thomas Sullivan and David Wieczorek; **Prof. Gordon P. Ramsey**

6. *Syringe Hydraulic robot:* Matthew Durfee, Christian Konopka, Michelle LIs and David Sack; **Prof. Maria Udo**

7. *Extacting Energy from Wave Motion*: Joe Berce, Mary Bucki, Walid Syed and William Zhe; **Prof. Robert Polak**

8. *Attempts at a Dyson:* Air Multiplier Chris Camarata, John Markos, Shane Romer, and Nick Tilelli; **Prof. Robert McNees**

9. *Photoelasticity and Stress:* Ethan Blackburn, Aleksander Weismantel and Lukasz Zak; **Prof. Thomas Ruubel**

10. *Static Friction Revisited:* Zach Ganger, Paul Kleinmaier, Ahmed Safdar, Brian Stone; **Prof. Aleksandr Goltsiker**

Appendix B: Poster presented at 2012 spring AAPT meeting

This work began as Freshman Project in spring of 2009. Two students, Benjamin Irvine and Matthew Kemnetz carried out significant research in experimental and theoretical areas. The details of their work is given in Ref. [Irvine-2012]. The following figure is a copy of the poster they had presented in 2012 Winter meeting of Am. Assoc. of Physics Teachers (AAPT) at Ontario, California.

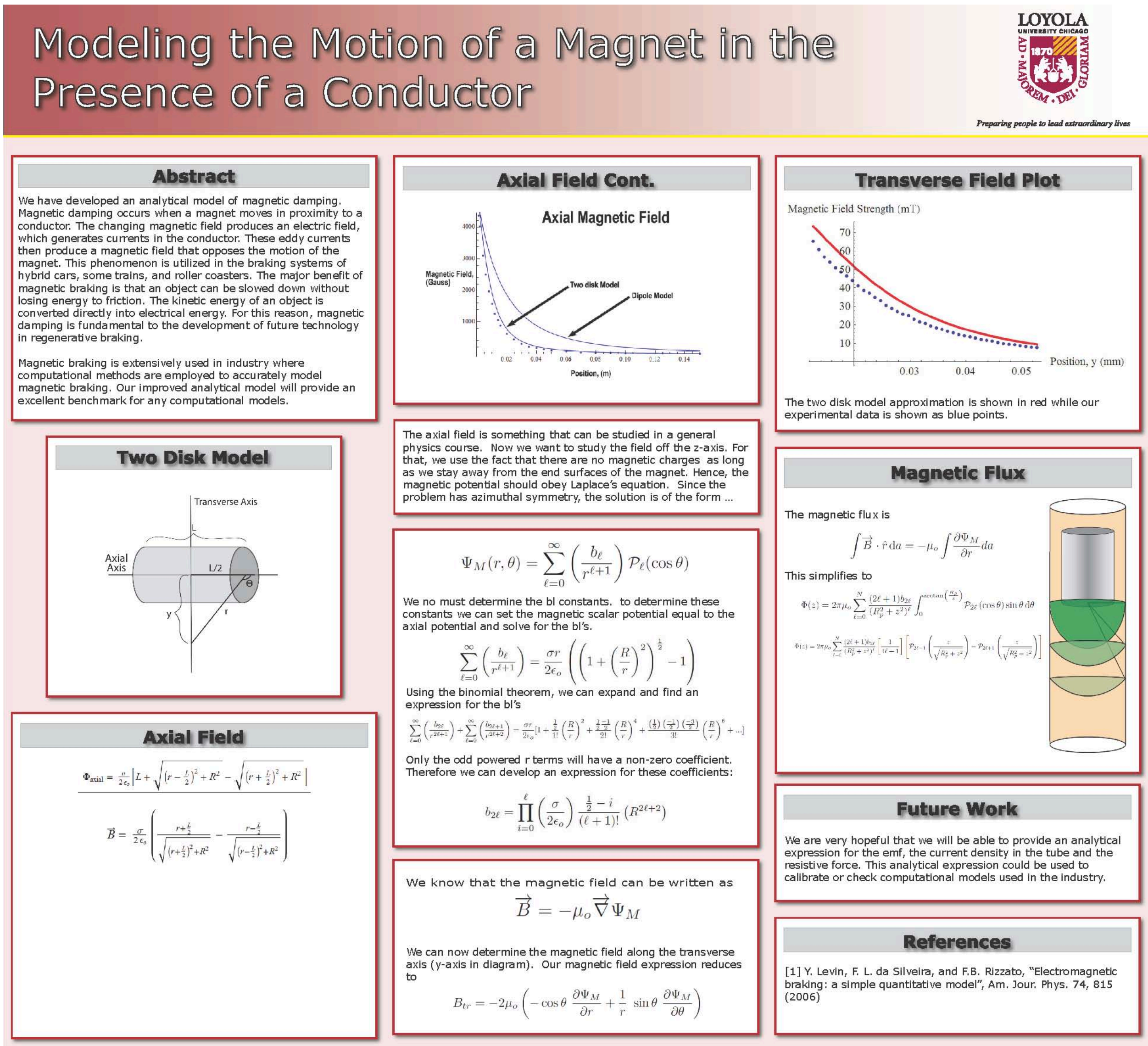

Figure 1: Poster presented at 2012 spring AAPT meeting in Ontario, CA.

Appendix C: National Study of the Impact of Undergraduate Research

In a Physics Department such as Loyola's, with its nationally-recognized, large, and diverse enrollment of physics undergraduate majors in an undergraduate-only Physics Department, research is essential [Hilborn-2003]. This has been recognized and documented in a series of studies. In 2003, the Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) released its final report in this regard. After conducting a national survey of undergraduate physics programs, SPIN-UP listed undergraduate research as one of the elements of a thriving undergraduate research Physics program [Hilborn-2003]. The report goes on to conclude that, Students gain experience working in teams and communicating their results, both orally and in written reports. The shared research experience gives the students a deserved sense of being part of the scientific community, not just passive consumers of science through their courses. Most departments recognize the importance of undergraduate research in building a sense of community within the department [Hilborn-2003].

Although it can be difficult to quantify the role of undergraduate research in regard to a students skill set and career choices, three large studies have attempted to shed light on this area [Guterman-2007]. These three studies each examined three different areas. One included in-depth interviews with students at four liberal-arts colleges. Another expanded this study for thousands of students at other institutions. The third study performed similar surveys with students, some of whom had received grants from the NSF for research. All three studies found similar cognitive and personal benefits for students, including understanding how scientists work, learning laboratory techniques, and gaining self-confidence [Guterman-2007]. And although it is difficult to quantify whether undergraduate research increases the likelihood of a student attending graduate school (some students in the surveys did find the reality of research tedious and difficult, and all researchers reported the difficulty in surveying students years after graduation), all three studies conclude that undergraduates learn and grow significantly from their research experiences.

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