

# Involvement of Undergraduate Students in Research: A Comparison of Course Research Components, Paid Research Activities, Student-Led Projects and Independent / Directed Study Courses

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## **Abstract**

Involving undergraduate students in bona fide research can provide multiple types of benefits. Whether students elect to pursue research careers or not, research experiences can be beneficial. Students gain an excellent resume item and interview discussion topic. They also gain experience in team participation dynamics and project management and the opportunity to put techniques that they have learned in the classroom to use. In interdisciplinary projects, they learn to work with those from other disciplines, gain an understanding of the challenges of doing so and gain an understanding of the vernacular of these other disciplines.

This paper presents an overview of multiple techniques for involving undergraduate students in research activities. For each type, a brief description and a discussion of both the benefits and drawbacks of the style is presented. From this discussion, a set of best practices is drawn.

## **1 Introduction**

Involving undergraduate students in bona fide research prospectively provides numerous benefits. It, certainly, exposes the students to the career potential of working in a research field. However, even for those that do not elect to pursue this route, research experiences can be highly beneficial. Students gain an excellent resume item and interview discussion topic. They gain experience with workplace-relevant topics such as team participation dynamics and project management. In many cases, they gain an opportunity to put techniques that they have learned in the classroom (that are difficult to fully conceptualize the benefit of in the context of a short exercise), such as code reuse, design styles and architectural principles, to use. Finally, in some cases, they have the opportunity to work with those from other disciplines, gaining an understanding of the vernacular of these disciplines as well as the challenges of interdisciplinary projects. As many real-world projects require the collaboration of those between multiple disciplines, learning how to work in a cross-disciplinary environment is a key skill to learn. Learning it, while learning discipline-specific skills, prevents students from later having to un-learn silo-style thinking.

This paper presents an overview of multiple techniques for the involvement of undergraduate students in bona fide research. Several types of involvement are discussed including the use of course research components, paid research activities, student-led projects and independent / directed study research-based course topics. For each type, a brief description is provided as well as a discussion of both the benefits and drawbacks of the style. Benefits considered include the impact on course material understanding, increased student belief in their own efficacy, student leadership experience and the acquisition of ‘soft’ skills. Drawback considerations include any negative perception of the approach, the effectiveness of the use of the approach (for a given period of time) versus other approaches, time and financial costs of the approach, and potential problems posed.

From this discussion, a set of best practices is drawn. These take two forms. First, recommendations as to the appropriateness of each technique for a particular application or scenario are presented. Second, a set of overarching principles for maximizing the value to students (and optimizing the value relative to time and financial costs) are discussed.

## **2 Background**

One of the oldest styles of learning is experiential education. The educational approach of ‘learning-by-doing’ has an extensive history. One example of this is apprenticeships, which have been used instead of or to augment formal education [1]. This style of learning has been used throughout history [1, 2]; however, more recently, it has been seen as a valuable departure from the now typical lecture-based instruction approach.

One form of experiential education is project-based learning (PBL) (which is also known as problem-based learning). PBL is a technique where students learn, as in an apprenticeship, by doing. Some [3] proffer that the benefits of this approach are so great as to effect national competitiveness on a global scale. PBL has been shown to be

effective across multiple disciplines. These include entrepreneurship [4], project management [5], computer science [6] as well as aerospace [7], computer [8], electrical [9] and mechanical [10] engineering. PBL has been shown efficacy across numerous educational and age levels [11, 12]. It can also provide ancillary benefits such as improved student creativity [13], self-image [14] and motivation [14]. It also has been shown to have workforce preparation [15], job placement [16], material understanding [15], academic program retention [17] and knowledge retention [18] benefits.

The university environment provides a number of prospective ways to use PBL. It can be incorporated into a conventional course (such as by including a course project [11]) or a PBL-style course could be developed. Students may, alternately, have a PBL experience through an independent or directed study [19] project, as part of a senior design experience [20] or via activities they engage in for extracurricular educational enrichment [19].

### **3 Undergraduate Involvement Techniques**

Multiple techniques for involving undergraduate students in research are now discussed. Each technique is introduced with a brief description. Then, an overview of the specific benefits and considerations of each technique is presented. Techniques discussed include course research components, independent and directed study research courses, student led projects and paid research efforts.

#### **3.1 Course Research Components**

Course research components can come in many forms. They can be used to achieve a variety of knowledge and skill learning objectives. They have also been shown to provide a number of soft skill benefits. In [21], work was presented that used a course research component to meet learning objectives related to project management.

Topics were identified in the ACM / IEEE Computer Society model curriculum [22, 23]. These topics included [21]:

- Team management
- Risk
- Project management tools
- Scheduling
- Quality Assurance
- Configuration management / version control / release management
- Measurement / Estimation
- Process models

The course research experience was included in the University of North Dakota's CSCI 297 course. CSCI 297 is an experiential learning opportunity. It has been refined from an open-format approach (as discussed in [21]) to a more well-defined format that includes pre-recorded video lectures (based on the 'flipped classroom' methodology), in class discussions and research project-integrated project management deliverables.

In the first iteration of this course (which was prior to the creation of the project management videos – during this iteration, students read the textbook to gain initial knowledge and then participated in in-class discussions), students participated in the OpenOrbiter small spacecraft development program. Each student selected one of the

project's software teams and acted as a project management consultant or team lead for this team. For the selected team, each student [21]:

- *Created a project definition document*
- *Created an overview of deliverables and their elements*
- *Created a work breakdown structure for the group*
- *Used the work breakdown structure for estimation*
- *Created a schedule for the group (including dealing with dependent tasks and fixed start/end date tasks, where applicable)*
- *Used Microsoft Project to build some of the foregoing*
- *Presented their work as a poster at a local event related to space robotics*
- *Broke in to two-person teams which each developed two operations-phase (risk / issue / change / etc. management plans)*
- *Adapted their plans based on supplied additional information that they were*
- *required to consider*
- *Provided critical feedback to their classmates via verbal discussions and anonymous feedback cards*
- *Interacted with team members from the team that they were supporting to gather information and gain buy-in for their proposed plans*

As part of the assessment of the course and the small spacecraft development program, students were asked to identify the benefits they received from course / program participation. Both pre- and post-surveys were conducted with the former focusing on benefits desired and the latter focusing on the benefits actually received. Figure 1 summarizes the number of students indicating that each area is a key area of benefit received.

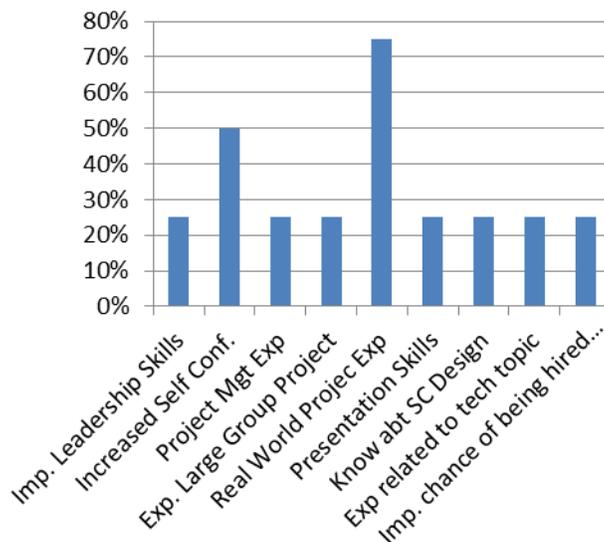


Figure 1: Areas of Benefit Identified [21].

### **3.2 Independent / Directed Study Research-Based Course Topics**

Independent (and to a lesser extent) directed study research experiences may involve a fundamental shift in the design of the research experience: the student participant may choose the research topic and goals, instead of a faculty member. This is, by no means, guaranteed (and course research components can certainly offer great freedom to students as well, within the context of the topic of the course); however, the format and nature of these courses is more amenable to student topic selection from a broad continuum of choices. In some cases, independent and/or directed study courses may be used in conjunction with larger projects that are either faculty-driven or student-led (see the following section).

### **3.3 Student-Led Projects**

Student-led projects offer the greatest degree of flexibility for student participants. These types of projects may start in response to an external stimulus (such as a design competition or other program) or simply based on students' desire to learn more about or work with a topic. These types of projects may also start with a goal of (or develop a goal of) business formation.

Considerable assessment has been performed surrounding the OpenOrbiter spacecraft development program. This assessment has been both formative and summative. Student participants were asked [24] what their goals and expectations for program participation were. Surveys were also conducted to determine what outcomes were being achieved [19] and what the impact of the duration of participation was on these outcomes [25].

In [19], significant average improvement from a short duration of participation was shown: 2 units or greater of average improvement (on a 9-point scale) for technical skill and spacecraft design skill and more than 1.5 units of improvement for space excitement and more than 1 unit for presentation skills and comfort. Undergraduates showed an average aggregate improvement (the summation of improvement in all five categories) of approximately 6.5 units, while graduate students showed an aggregate average improvement of just over 6 units. The percentage of students showing improvement was greater for undergraduate students in technical skills and spacecraft design skills, while a greater percentage of graduate students showed improvement in spacecraft design skills, presentation skills and presentation comfort.

In [25], very strong correlation between participation time and enhanced technical skills (0.85), spacecraft design skills (0.84) and aggregate improvement (0.89) and strong correlation between participation time and enhanced presentation skills (0.63) was shown. The results for undergraduate participants didn't show positive correlation between participation duration and skillset improvement, suggesting that benefit may be obtained quite quickly and not enhanced significantly over time. An alternate interpretation is that undergraduate students' metrics for the skills change as involvement helps them to learn the actual scope of the field (reducing their perception of their skills

and abilities therein). A study generalizing these results to a national level is also underway.

### **3.4 Paid Research Activities**

Paid research opportunities for undergraduate students are not unusual. These activities, in the context of the university environment, can be largely divided into two categories: faculty-led research and faculty-mentored research. In the former, the student plays a role in a faculty-conceived and faculty-directed projects. Depending on the nature and scope of this type of a project, the role and independence of the student can range from being a proverbial cog in a larger machine to having a significant impact. In the later approach, a student or group of students devise a project that is of interest to him / her / them and reviewed (and possibly refined) by a faculty mentor. Both types of projects are analogous to previously discussed ones: the faculty-led projects share significant similarities with course-integrated research experiences and independent/directed study projects (presuming a pre-selected topic is used). Faculty-mentored projects have significant similarities to student-led projects (which may, but are not required by definition to be, faculty mentored). Work on the assessment of the impact of payment on the student research experience is ongoing.

## **4 Project Risk and Best Practices**

While the data presented has demonstrated that student research experiences can be very effective in generating desired outcomes across multiple learning objectives, there are numerous prospective pitfalls that can befall a student research experience. While technical, logistical and external issues can certainly befall a project, one of the greatest sources of risk factors is the student participants themselves.

The Student Qualitative Undertaking Involvement Risk Model [26] and its extension [27] have documented these sources and discussed risk mitigation in the student-involved project context. Figure 2 provides an overview of the risk factors that are present, including both special risks for student-involved projects and typical risks that are exacerbated by student involvement.

While the risks may be atypical, the strategies that can be used to identify and manage them are well defined. The discipline of project management (see e.g., [28]) offers no shortage of input in this regard.

## **5 Conclusions**

This paper has provided an overview of work that has been performed on student research opportunities and their impact on student participants. It has divided these experiences into four categories based on the nomenclature typically used in the university environment; however, significant overlap has been noted between these categories (and the ability for a research project or experience to span or fall under multiple categories is undoubtedly possible). Each category has been discussed and empirical results have been presented, where available. A discussion of student involvement risk has also been presented.

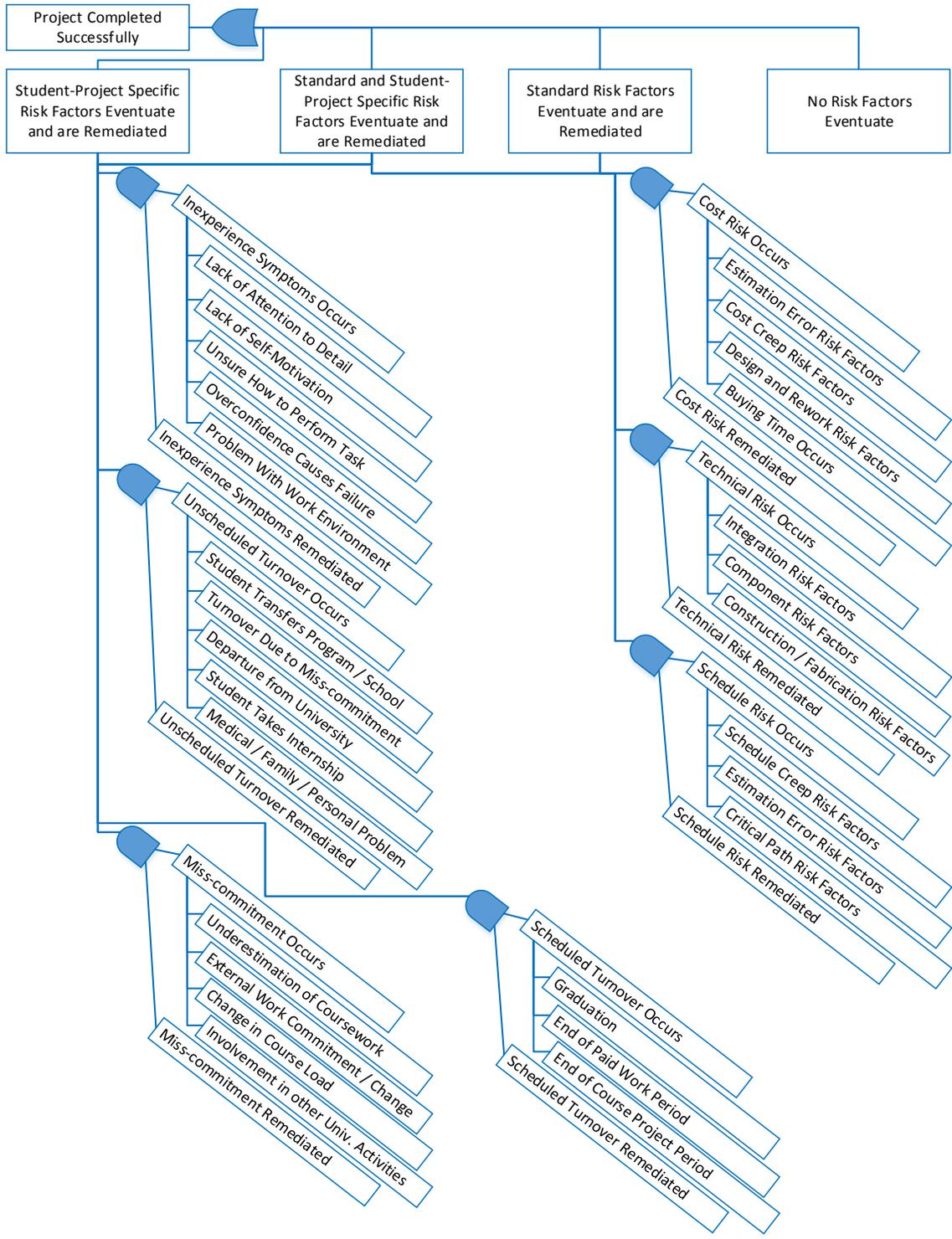


Figure 2: Extended Student Qualitative Undertaking Involvement Risk Model Diagram [27].

The involvement of undergraduate students in research offers great potential for them to gain ‘leading’ or ‘bleeding’ edge experience in topics of interest to them and their

prospective employers. It also provides students with an opportunity to gain a large variety of soft skills that may be more critical to their success in the ‘real world’ than particular technical skills.

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