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Development of an Online Course in Research for Undergraduate Students

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Abstract

This Work in Progress paper will cover the development of an online course in research practices for undergraduate students. Active participation in research is an important part of experiential learning, which can help to prepare students for careers in a variety of settings including industrial R&D departments, academia, and government research labs. Undergraduate students' research experiences may be limited in their value, however, by the learning curve students face as they begin to conduct research. The quality of their training may also be limited, with some receiving excellent training and orientation from a strong research lab or faculty mentor, and others receiving little guidance. In order to better prepare undergraduate students for research, faculty members in different departments at Kettering University, a midwestern STEM-focused institution, received an internal grant to develop a class in research for undergraduates. This class, which is designed to be offered online either for cohorts or for individual students as an independent study, contains information and resources on a diverse range of issues such as motivation for research, research ethics, planning a research project, conducting literature searches, experimental procedures, keeping lab documentation for various types of projects, data analysis, technical writing, intellectual property, and issues relevant to scoping out one's own research project.

This paper will give the background for the course development, evaluation of the required content and decisions on structure and format, and describe the various modules in the course. It will also describe the future plans for deployment, evaluation, and continuous improvement of the course, and suggest ways in which it could benefit a wide range of undergraduate students in different disciplines.

Introduction

Active participation in research is an important part of experiential learning, which can help to prepare students for careers in a variety of settings including industrial R&D departments, academia, and government research labs. Through undergraduate research experiences, students can discover what research looks like in their discipline, and determine whether it is something that they want to pursue. This could lead them to apply to graduate school and gain further training and experience in research, or it might show them that they want to pursue other paths, which is also of value.

Learning to do research involves much more than walking into a lab and sitting down at a computer, desk, or lab bench to start work. In addition to the paramount issues of safety and ethics, students need to know something about the research process in order to carry out effective work and learn what they hope to from the experience. This knowledge can be gained through the instruction of a mentor, either a professor or a more senior student; however, the quality of that instruction varies, and this individual process is time-consuming. Having some kind of course in the research enterprise, geared to undergraduates, would be a useful option for students to learn more about the fundamentals of research, and allow their mentors to use time wisely by providing more in-depth guidance on their specific projects. In this paper, we describe the development and structure of an online course in research for undergraduates, and discuss plans for deploying the course.

Background and Motivation

Undergraduate research experiences are widely acknowledged to have multiple benefits, as seen by both professors [1] - [5] and students [6], [7]. Such experiences need to be well-designed, however, in order to realize those benefits. This can include the design of physical laboratory facilities [8], design of the program and projects [9], [10], and enhancements to physical and organizational infrastructure [11]. Well-structured research experiences for undergraduates typically include some form of mentoring or guidance, as discussed in [5], [10], [12], [13]. They also have a means of assessment or evaluation built in, both to assess students' progress and to evaluate the program itself [14], [15]. One key issue in such programs is what should be taught to students and how it should be done. Research skills are typically imparted through individual mentoring, as described in [5], [10], or simply through the process of conducting research [16]. At times, students may experience research within the context of a class. One example of this is a course focusing on a senior research project for physics students, which integrated research skills with a specific project [17]. However, in this context, the focus is more on the students' learning by doing, rather than extensive instruction in the research process as a preparation to carry out research. In a few cases, some form of structured teaching of research topics has been carried out

through formal seminars, as in [18]. Such formal instruction can be very useful to students, as it provides them with the skills they need to take full advantage of their research experience.

The work described in this paper is intended to fill this need, by creating a structured course that students can take prior to engaging in research. The course is implemented online, and can be conducted asynchronously with a group of students, or can be used for a student to learn as an independent study. The course learning objectives began through a multi-institution Faculty Learning Community, with the detailed development of the course taking place at a single institution, Kettering University, under the auspices of a grant from the university's teaching center.

Course Learning Objectives and Prerequisites

The course learning objectives were initially set forth within a Faculty Learning Community (FLC) focused on undergraduate research advising. This FLC included both two-year and four-year institutions, with faculty coming from a range of different academic disciplines. Discussions among the faculty members focused on what aspects of research were most important and needed to be understood before students were able to be effective on research projects, and were common across disciplines. Some of these aspects of research included ethics, the importance of safety, keeping good documentation, and the fundamental nature of research itself, as a way to find out things that are not yet known.

These course learning objectives are:

1. Understand the importance of scientific ethics and acting ethically.
2. Understand the monetary and temporal aspects of research
3. Know research practices for effectively working independently and in a team.
4. Perform a literature review relevant to a research topic.
5. Formulate a research question and construct a research hypothesis.
6. Design experiments inclusive of appropriate controls.
7. Handle data, materials, and equipment appropriately.
8. Maintain a high-quality laboratory notebook.
9. Choose appropriate methods for effective and comprehensive data analysis.
10. Comprehend the importance of research results while drawing sound conclusions.
11. Communicate results and background information verbally and in writing.
12. Suggest ideas for future work in a specific discipline.

When deciding on course prerequisites, several issues were discussed. The purpose of prerequisites was considered in some depth. The faculty creating the course felt it was important to promote wide access to the class, which argues in favor of few if any prerequisites. However,

it was also important to ensure students who take the class have the necessary preparation to be successful, which could argue in favor of some form of prerequisites. In discussing these competing priorities, it was decided that the formal prerequisites would be minimal, and that there would be several requirements that could be described as “soft” prerequisites, as they referred to students’ attitudes.

The only formal requirements to take the class, therefore, will be the approval of the instructor or a mentoring faculty member, and a GPA of 2.0 or greater. The “soft” prerequisites were listed as an openness to learning a variety of new skills and a positive attitude towards research. While these are not something that can be formally measured or assessed, they can serve as a guideline to faculty members in deciding whether or not to approve a student who has asked to enroll in the course, and as a means of setting expectations for students who are considering enrollment.

Course Structure

The course is structured as a set of six modules. These modules could be completed as weeks of a class, which would fit into a summer term or as part of a standard academic term. They could also be deployed as part of a Research Experience for Undergraduates (REU) program or some other form of research experience.

The six modules are listed below.

1. Introduction to Research: Motivation, Ethics, and Process
2. Research Practices
3. Literature Review
4. Designing and Conducting Experiments
5. Analyzing Data, Drawing Conclusions, and Suggesting Future Work
6. Understanding the Research Enterprise

Each of the modules contains its own learning objectives, an introduction to the module, a set of learning resources, and a set of learning activities. Several rounds of revision were undertaken to ensure that these were all aligned, and that options for learning activities were available for either individual work as independent study or for an asynchronous class with multiple students.

In the development of the course, the team decided to seek out and utilize existing resources wherever possible. This allowed multiple perspectives to be presented, used time efficiently, and resulted in the use of high-quality content. An undergraduate student was employed to assist in gathering resources.

Each module is briefly described, with typical learning resources indicated.

Module 1: Introduction to Research

The purpose of the first module is to help students understand why they might want to conduct research in the first place, both to motivate their research work and to motivate them in the course, and to give them some key information they need to start on research. This is particularly important if they are starting a research project while they are taking the course.

Some of the reasons that are presented for conducting research are curiosity, the wish to solve problems, salary considerations, and desired career paths. Students are asked to reflect on their own motivations in the learning activities for this section.

After examining research motivation, students examine the value of research to society. The specific focus is on the value of the research enterprise within the United States, as the university

developing this course is located within the United States. However, this could be generalized to other contexts, as many problems are international in scope, and many countries actively promote research.

The next section of this module focuses on various codes of ethics for different professions, with a focus on relating it to a student's own ethical principles. The goal of this is to develop researchers who have a strong ethical grounding for their work. After this, there is a section in which students complete training through CITI on the responsible conduct of research.

The final section of the module focuses on the research process, with the various steps that need to take place in order to generate new knowledge. By the end of the module, it is anticipated that students will be able to start on their project(s), although many of the items they were introduced to in this module will be developed in more depth in later ones.

Module 2: Research Practices

In the second module, the course goes into more detail on how to go about conducting research, in terms of actual activities that take place. It begins with a section on dividing projects into distinct tasks, then covers sections on effort planning, scheduling, and effort reporting. It next contains sections on practices important to working with others and progressing, including teamwork, file sharing practices, seeking help, staying on task, and concludes with some ethical case studies.

This module is intended to help students seek how to actually take their motivation, enthusiasm, and newfound understanding of the overall research process and begin to work on the distinct tasks that need to be done to progress on a project. It contains a recognition that sometimes tasks will take longer or shorter than planned, as much is uncertain or undetermined in research projects, but emphasizes the necessity of having some kind of schedule and means to stay on track. The emphasis on seeking help - when and how to do so - is included as part of the recognition that undergraduate research is a learning experience, and students are expected to need help along the way.

Module 3: Literature Review

The third module focuses on literature reviews. It begins with a section on identifying discipline-relevant research databases, then goes into the search process itself. Additional sections cover the evaluation of quality of sources, reference management software and reference formatting, and summarizing papers. It then has a section on plagiarism; while plagiarism is an ethical topic, it is covered in much more detail in this section, expanding on the material on ethics that was previously covered.

This module then has sections on identifying and constructing research questions, based on the literature review, and on hypotheses. By the end of this module of the course, students should be able to review literature and identify unanswered questions. While in their initial research experience they are likely working on a project that already has questions identified, the ability to come up with their own questions is an important step towards increasing levels of independence as a researcher, as well as helping them to understand their existing project better and set the work that they're doing into a broader context.

Module 4: Designing and Conducting Experiments

In the fourth module, students learn more about the design and execution of experiments. Again, while they may be initially conducting experiments that were designed by a faculty member or more senior student, the goal is to provide them with the knowledge and ability to move beyond their initial project and into increasing levels of sophistication.

The material in this module begins with sections on experimental procedures, instrumentation and software, and controls for experiments. It then covers how one can identify the resources needed for a particular project, whether that is hardware or software, and how to properly handle data. Safety training is also included, with the goal of supplementing whatever training a student had already received in their lab, and a section emphasizes the safe use of equipment.

Further expanding on the handling of data, additional sections cover the importance of detail and completeness, keeping a proper lab notebook, and the different types of electronic lab notebooks that are available for use.

Module 5: Analyzing Data, Drawing Conclusions, and Suggesting Future Work

In the fifth module, students learn how to analyze data of various types. It begins with a section on statistics and hypothesis testing, then covers curve fitting and interpretation. Other material covers software, with a focus on different tools that can be used to analyze and visualize data, and then talks about analysis of the data, how to compare results, and the formatting and presentation of data. This module also includes how to present results through oral presentations and technical writing, and covers the issue of future work.

By this point in the course, it is assumed that students either have data or some understanding of what data they might have. While the course cannot go into full depth on technical writing, as it is a course in its own right, it does provide a review of some basic concepts and techniques in technical writing. It is assumed that students will, between their other writing courses and this module, have enough information that they would know how to start on the writing of a technical paper for a suitable conference, journal, or other venue within their discipline.

The inclusion of a section on future work is intended to foster an understanding that research is a process, and that there is not a single endpoint of knowledge generation or learning - that there will always be new questions arising from previous work, and how to identify and explain those. This ties back to earlier items, such as the motivation for research that involves the desire to learn new things, and sets the stage for the sixth and final module.

Module 6: Understanding the Research Enterprise

The sixth and final module, in a sense, closes a loop and goes back to the material in Module 1. In that first module, students learned about the value of the research enterprise to society and to the country, as part of the motivation for why research is done. In this module, students learn more about the research enterprise as a whole. It covers the structure of research or project proposals, funding agencies, the budgeting and acquisition processes involved in management of research projects, and issues of confidentiality and intellectual property that could be generated in a project. Confidentiality was touched on previously, when learning about ethics in research, but is explored in more depth at this point. Furthermore, students have the opportunity to look into funding agencies that provide grants and contracts relevant to their work.

By this time, students should presumably have learned more about their desire to carry out research. Some of them may be interested in pursuing it further than a single project, possibly in graduate school; this module would be one element of preparation for doing so, and could assist students who want to write proposals for competitive research fellowships such as NSF's Graduate Research Fellowship Program (GRFP). Other students may not want to pursue research beyond their initial experience; however, understanding the research enterprise as a whole may be useful to those who could manage research teams in industry or have other peripheral involvement with the research enterprise.

Course Deployment and Next Steps

At this point in course development, materials have been compiled, and course scope and sequence documents have been drafted. One module in the course will be put online and deployed for testing.

In the testing process, a student will be asked to access the learning resources and complete the learning activities - in short, to do exactly what they would do if they were taking the course. They will then report back to the team on issues, problems, or areas of confusion. This feedback will be used to revise that first module, and will inform the finalization of the additional modules.

Upon the complete deployment of the course, it will be made available to faculty at the university to teach to their students, either in groups or individually. It is anticipated that

continuing maintenance will need to be done at times, as new resources are made available and existing ones become obsolete or unavailable.

Conclusions

In this Work in Progress paper, we have described the structure and content of an asynchronous online course in research for undergraduate students. When deployed and utilized, it is anticipated that this course will provide undergraduates with a good grounding in research, and will supplement mentoring from their research advisors. By providing a clear structure and curated set of resources and activities, faculty mentors can concentrate their time and attention on providing project-specific and discipline-specific information and training to their students, thus better utilizing their time.

As the course is deployed, it will be evaluated and improved where necessary; future publications are anticipated to cover this evaluation and any necessary improvements.

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