JUST IN TIME RESEARCH: THE ADVANTAGES AND PITFALLS OF A STUDENT-LED INTERDISCIPLINARY UNDERGRADUATE RESEARCH EXPERIENCE

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ABSTRACT

This paper describes the advantages and potential pitfalls for interdisciplinary undergraduate research in computer science and chemistry programs. We contrast the traditional, mentor-led research approach in which a professor initiates and guides the research process vs. a student-led approach that requires the students define the research questions and goals in the process of conducting the research. We discuss our experiences with both approaches with an interdisciplinary team of students from the computer science department and chemistry department at Drake University, a private, small liberal arts college located in Des Moines, Iowa.

INTRODUCTION

There is little doubt that undergraduate research experiences are beneficial to students' education. Such experiences have been shown to increase retention, promote graduate study, and encourage students to think scientifically [5].

Chemistry and computer science have tremendous potential for synergistic collaborations in applications. Software can allow for various aspects of chemistry to be more engaging and easier to understand through applications such as molecular modeling and visualization [8]. Students studying chemistry can harness the power of computer simulation and analysis to further investigate the cutting edge of their field. Students of computing can learn of practical applications for software development. As an alternative to programming uninspired textbook exercises, exercises that utilize scientific applications have been shown to be highly successful in engaging students in computer science [3, 6]. Furthermore, students working in interdisciplinary teams have the opportunity to develop communication and teamwork skills with students having diverse expertise — conditions which more accurately reflect both software development and scientific research outside of the undergraduate setting. In particular, there is a recognized need among those at a wide variety of research institutions for a better understanding of how to construct correct and maintainable scientific software [7], highlighting the particular importance of collaboration among natural and computational scientists.

In this paper, we relate some of our trials, errors, and successes in directing interdisciplinary undergraduate research according to two models: a traditional, professor-led model and a completely student-led model.

	Mentor-led Research →	Student-led Research
Tasks	Assigned by mentor	Students learn content as needed
Research Content	Specific, narrow research question	Broad, general research question
Pace of Development	Rapid, planned, predictable timeline	Slower, less-predictable timeline
Likely Products	Peer-reviewed research paper	Regional research paper, student ownership, foundation for future research

Figure 1: The continuum of undergraduate research projects that range from mentor-led to student-led. Where a project is on the continuum often depends on how much control and input students are given with respect to the direction of the research.

MENTOR-LED AND STUDENT-LED RESEARCH EXPERIENCES

While the benefits of incorporating undergraduate students in research have been widely reported as beneficial, the specifics of how the research is conducted can be wildly different depending on considerations such as the size of the school and departments, the aptitude of the students, and the particular time restrictions on the professors. In practice, there is a spectrum of how involved the student researchers are in the design of the research project itself ranging from mentor-led research to student-led research (Figure 1). Mentor-led research projects are typically initiated by a professor and based on an established area of expertise. The projects typically have a narrow focus and introduce students to the research process, but they often don't give the students much control over the direction of the research. Conversely, open-inquiry or student-led experiences often put the onus on the students to establish the research agenda, design experiments, and conduct the research under a mentor's tutelage.

Mentor-led Research Experiences

Mentor-led research programs are highly targeted, typically planned start-to-finish by the research adviser, usually well in advance of the arrival of students. In these programs, the mentor provides the context for the problem to be investigated, including motivation and past work. The project to be undertaken is typically highly targeted, following the mentor's research plan, which often depends on the priorities of funding agencies.

The advantages of this approach are numerous. This approach mirrors what students are likely to experience in graduate studies or as baccalaureate or master's level technicians in industrial research. The student finds him or herself on an established research path and is usually able to make rapid progress, since the overall direction of the research has been dictated by the mentor and the specific path has frequently been blazed by prior students. This rapid progress allows students to become co-authors on peer-reviewed publications and likely aids the mentor in sustaining funding.

This approach also has a few key drawbacks. Students may not gain substantial experience in identifying an important scientific problem, nor are they typically forced to wrestle with the design of the methodology of the project, including the necessary literature review. Critically, students may perceive that research isn't significantly different from classroom work. In summary, then, mentor-led research experiences directly advance the research agenda of mentors while preparing students well for future mentor-led work, but may not prepare students as effectively as possible to be research mentors themselves.

Student-led Research Experiences

Conversely, student-led research is fundamentally exploratory rather than targeted. Students engage the research process at the beginning: identifying an unsolved problem. The students then determine an approach to take in advancing toward a solution to that problem, and execute that approach. This approach more closely mirrors the role of a principal investigator.

At the undergraduate level, this approach is essentially educational in nature and may not lead to fast results. By design, this approach teaches the research process itself more deeply than the mentor-led approach. Students are allowed to choose topics of direct interest to them and, critically, are allowed (and indeed practically required) to learn from their mistakes. The student-led research approach also parallels the increased use of active learning across STEM curricula, which has been shown to broadly increase student performance [2]. Innovation is required at the beginning of the research process, rather than hoping for the students to learn to innovate as they are directed in their project. The ability of students to choose their own research directions means they are able to select a topic of particular interest regardless of whether or not their educational institution hosts an expert in that field. Groups of students who choose a project of mutual interest may be more capable of working together productively. All of these advantages have potential implications for education, performance, and retention in the sciences.

This approach has a few disadvantages. First, the pace of development will likely be slow in comparison to a mentor-led approach. The students need to learn by making mistakes, and identifying the scope of the project and identifying small, achievable goals will take time as well as guidance from the mentor. The projects that students select may not fit into their advisers' research agendas. The results — or at least the initial, tangible results — of this approach may not be suitable for publication in a top-tier journal; instead, a regional or undergraduate conference may be a more reasonable goal.

There are also a few characteristics of student-led research that are unique, and aren't easily classified as advantages or disadvantages. For example, the role of the mentor in a student-led approach is more of a guide or a coach than a task-master. The professor helps students form and guide their research agenda and may suggest short-term goals. In this sense, the mentor becomes more of a peer for students, rather than a hierarchical figure. Furthermore, the time needed to manage the meeting and set agendas can be controlled as needed, which may be a critical consideration for professors at primarily undergraduate institutions.

OUR EXPERIENCES WITH A STUDENT-LED INTERDISCIPLINARY RESEARCH PROCESS

We observed the advantages and disadvantages of both mentor- and student-led research approaches first-hand in our mentorship of a joint chemistry and computer science research team. Our goal was to allow chemistry and computer science students to collaborate on a chemical application of computer science in order to foster cross-domain learning and communication. Our approach to incorporating students from both chemistry and computer science into an undergraduate research experience was to simply invite eight top junior-level students from our computer science and chemistry programs into a voluntary research experience. These students all had a relatively high GPA ($\geq 3.7/4.0$), and were evenly divided between male and female, but the primary selection criterion was the potential to engage deeply with research as observed in prior courses. We offered no incentives other than the likelihood of positive recommendation letters and the opportunity to research something beyond a traditional course. Over the course of two years, our research group presented at three regional conferences and produced multiple senior capstone projects. Our approach was initially somewhat more mentor-directed, but we found greater student engagement and productivity as students took on more of the planning; we therefore allowed the research arc of this group to become entirely student-led.

A Mentor-led Approach

Initially, in a mentor-led approach, we suggested that our students investigate the use of graphics processing units (GPUs) in dynamical simulations of biomolecules, in particular for coarse-grained modeling of protein dynamics [1] as this was an area of study close to our areas of expertise. As a stepping stone and per our guidance, our students constructed a traditional (non-GPU) molecular dynamics program incorporating bond stretching and van der Waals interaction potentials, along with the code to read initial protein structures from the Protein Data Bank. Though this work resulted in a presentation at a regional conference, we found our students needed more guidance in how to proceed than we would have liked. In particular, we found our students asking us what to do next, rather than they themselves identifying new directions.

The Transition to Student-led Research: What Do You Want to Do?

As a result of the feedback our students gave us, in the subsequent academic year, we encouraged our students to identify a topic that they found interesting. Together, the students determined that using machine learning algorithms (specifically support vector machines) to identify splice sites in RNA sequences would have the biomedical import the chemistry students desired and the focus on machine learning the computer science students required. While this was far from our areas of expertise, we felt that we could guide the students through an open-inquiry (student-led) approach to the research.

As a stark contrast from the mentor-led approach employed in the previous year, the weekly meetings were short and refreshing. Instead of students asking us professors what to do next, the meetings were an open dialog of how to tackle problems, strategies to find valuable information, and making short-term goals. We let the students ask most questions, and our role in the discussion was simply guiding the meeting. In order to mentor our students in the research process, we asked guiding questions (e.g. "What have you been doing? What's been going well? What's been difficult? What's next?"). During each meeting, we further asked students to explain their decisions at each stage. This ensured that students critically evaluated their progress, rather than simply seeking to make progress before the next meeting. This structure for our meetings was similar in many respects to just in time teaching (JiTT).

Just-in-time Research

Just in time teaching [4] — JiTT — is a teaching and learning strategy in which students are encouraged to submit questions about a topic or reading several hours before a class meeting. The instructor can tailor the lesson "just in time" to address the questions from the students. The JiTT strategy is purported to work well in maximizing the efficiency of a classroom session, gives constructive structure to out-of-class activities, and sustains enthusiasm amongst students[4].

A significant advantage of conducting a research group with this strategy ("just-in-time *research*") is that it allowed us to implement a fully student-led research approach in a manner that used time efficiently for both professors and students. The just-in-time research approach allowed us to give the students specific direction for week-to-week meetings (e.g. explore a new approach and come back with questions), but did not require substantial advance preparation on our part. This was a deciding factor in making a research program relatively far from our research expertise feasible in the setting of our teaching-focused, primarily undergraduate institution.

Educational and Research Outcomes of Our Interdisciplinary Collaboration

This just-in-time, student-led, interdisciplinary research group was successful from both educational and research perspectives. Our students presented their work at three regional conferences and, upon their graduation, left the project at a point where future students could extend it to a level appropriate for publication in a peer-reviewed journal. More importantly, our students learned to collaborate across the boundaries of chemistry and computer science. Our students not only communicated across domain boundaries, but learned across them as well.

In particular, by the end of the experience, the chemistry students taught machine learning algorithms to chemistry faculty in their senior capstone course, while CS students had taught themselves both the theory and programming of support vector machines, a widely-deployed machine learning technology.

FINDINGS AND SUGGESTIONS FOR THE FUTURE

The student-led, just-in-time research approach was particularly useful for allowing students to engage deeply with topics pertaining to their interests, regardless of whether those interests align with the expertise or existing research programs of their advisers. In our case, students developed an increased sense of ownership and investment in the project. This, in turn, allowed us to shift our focus from directing the students along a particular path of research to teaching students the methodology of research itself. Since the initial exploration described in this manuscript, each of us has launched multiple student-led research projects, resulting in numerous local and regional conference presentations. Importantly, many more students are currently conducting authentic research projects than we could support with a traditional mentor-led approach.

In conclusion, we recommend student-led interdisciplinary research collaborations as a component in a strong undergraduate STEM curriculum. In this approach, students and faculty mentors are true peers in the research process. The experience of conducting research becomes universal, an exciting process of discovering, learning, and then sharing something new that was discovered.

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