A CASE STUDY OF A STUDENT-LED RESEARCH GROUP

SUMMARY: We present a case study of a multidisciplinary undergraduate-led research group that provided research experience to undergraduate students at Queen's University. By reflecting on the case study we identify guidelines to help reproduce and improve the undergraduate research experience.

By **ASHLEY MICUDA**[1] <amicuda@uwo.ca> and **RYAN MARTIN**[1] <ryan.martin@queensu.ca>

[1]Department of Physics, Engineering Physics & Astronomy, Queen's University, Kingston, ON, Canada

ASHLEY MICUDA WAS A FINALIST IN THE 2022 CAP BEST OVERALL STUDENT ORAL PRESENTATION AND RECEIVED 1ST PRIZE IN THE DIVISION OF PHYSICS EDUCATION

Despite efforts to integrate research into curricula, many STEM programs lack accessible research opportunities [1]. Yet, providing research experience to undergraduates enriches their academic experience [2]. Undergraduate physics education often fails to expose students to current research [3] despite approximately 48% of physics undergraduates continuing to graduate school [4]. Traditional research opportunities, such as final year thesis and capstone projects, or summer research opportunities may be limited to students already excelling [5], thus restricting the pool of potential researchers according to pre-existing biases. Expanding research experience through alternative pathways could aid in making research more inclusive and accessible to a broader range of students.

A STUDENT-LED RESEARCH GROUP

This case study reflects on our work to build an undergraduate-led research group that developed an epidemiological model for the spread of COVID-19. This project started in summer 2020, primarily as a way to occupy undergraduate physics students hired as summer researchers at Queen's University just before the pandemic closed most physics research labs. In order to learn about the pandemic while developing skills that would transfer to physics, we proposed that the undergraduate students develop a Monte Carlo simulation to model the spread of COVID-19. The graduate students, postdoc, and faculty in the research lab provided support. As the summer progressed, more undergraduates from several departments joined the group which continued for four years. The students obtained grants to fund stipends, traveled to conferences, and published an article [6].

In this article we describe how we built this group and reflect on how it benefited the undergraduate students in order to extract guiding principles to replicate and improve this experience. Through reflection and through a survey administered to members of the group, we identified eight student learning outcomes (SLO) from this project, shown in Table 1, which will be highlighted throughout this article.

TABLE 1

Skills and learning outcomes determined by surveying the students to find out the benefits that they found from participating in the research group.

	Student Learning Outcomes (SLO)
1	Conduct a literature review
2	Learn and/or improve programming skills in Python
3	Work as a group
4	Mentor and educate peers
5	Collaborate on a complex software project with version control
6	Disseminate research findings
7	Apply for research funding

FORMATION AND EVOLUTION OF THE RESEARCH GROUP

The students first conducted a literature review to assess existing COVID-19 modeling approaches (SLO1), which revealed that Monte Carlo agent-based models were not used often. Instead, less computationally intensive models, based on differential equations, were more common due to their simplicity. It was thus suggested that, as a first "assignment", students should try to develop a simple Susceptible-Infected-Recovered (SIR) differential equation-based model to gain a basic understanding of epidemics [7]. The students were encouraged to develop code collaboratively, teach each other, and review each other's work using GitHub (SLO2, SLO3, SLO4, SLO5). The version-controlled code is now publicly available on GitHub [8]. Simultaneously, the undergraduate students contributed code to the Monte Carlo simulation following a framework that the graduate students designed.

After four months, the model was advanced enough to extract meaningful results and the students decided to continue working on the project throughout the school year. Additionally, the group expanded due to interest from undergraduates in several departments from word of mouth (SLO8). Each student pursued a sub-project of their choice, usually by adding a feature to the simulation, such as vaccinations, and then researching its effects to gain publishable insights. One student assessed how to optimize capacity restrictions leading to the group's published paper. Each project was student-driven, with individualized goals, supported by peers, and could be completed at a pace adapted to the student.

The undergraduates organized weekly meetings where everyone was encouraged to discuss their work from the week, ask questions, and schedule additional meetings for individualized help. This provided an opportunity to practice presenting research in a low-stakes environment and receive feedback.

The undergraduate students also applied to the Queen's Arts & Science Undergraduate Research Fund and received over $10,000 over three terms to cover the cost of conferences (SLO6), publications, and stipends. The students learned how to develop a research proposal with a budget and manage the research funds (SLO7). The group's work was presented three times at various conferences, including CAP 2022 (SLO6), by three different undergraduate students and a paper was published with all students involved in the group [6].

Graduate students provided oversight on the programming and sub-projects, asking questions during group meetings, and suggesting ideas to keep students on track (SLO4). Graduate students also acted as a review board for presentations, grant applications, and formal scientific publications. While the group was focused on the undergraduates, a strong emphasis was also placed on providing graduate students with the opportunity to gain leadership and mentoring experience. In total, 12 undergraduates and six graduate students participated in the group.

Figure 1 shows a diagram of the process that we envisioned to develop sub-projects as new undergraduate students joined the existing research group. While the goal for most of the students was not to ultimately write a paper, thinking of the sub-projects as having the potential to lead to a publication made them more meaningful and allowed us to think of a structured approach for the SLOs that may be useful for replicating the experience.

A survey was conducted to allow the group members to reflect on the positive outcomes from their involvement with the group. Responses included:

- Improved oral communication skills
- Large contributor in finding a research position
- Improved programming skills and software development
- Connecting and learning from people in other disciplines
- Valuable mentoring experience
- Learned about modeling

Five of the seven original undergraduate students from the group have continued to graduate school.

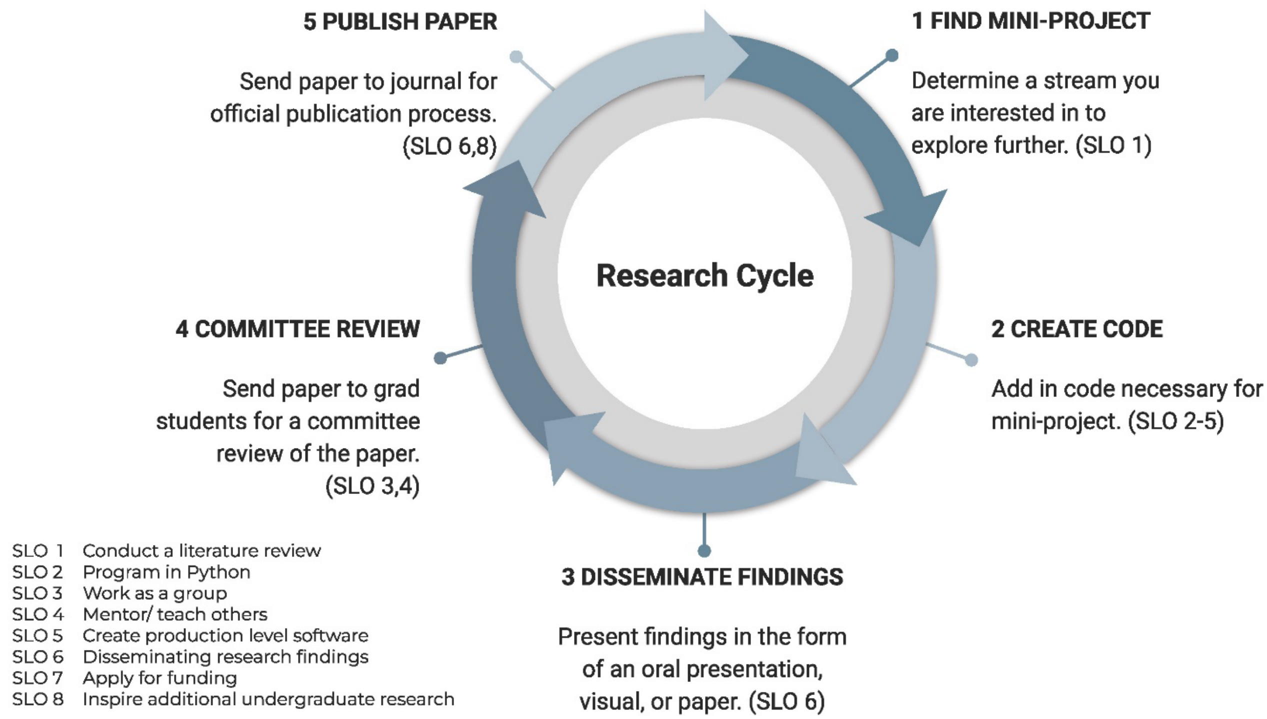

Figure 1. The research life cycle of the group, highlighting the major stages of general research and where each student learning outcome (SLO) fits to highlight the skills learned during the research process.

CONSIDERATIONS IN DEVELOPING AN UNDERGRADUATE-LED RESEARCH GROUP

Reflecting on our experience, we introduce here some guidelines that we think are helpful in building an undergraduate-led research group.

DEVELOPING A SUPPORTIVE STRUCTURE FOR RESEARCH ALONG A BROAD TOPIC

By far the most challenging aspect is to develop the project to the point where students can join the group to take on a sub-task. In our case, this required a dedicated faculty member motivated to provide the experience, graduate students willing to volunteer their time, and motivated undergraduate students. The topic of developing a COVID-19 simulation code worked well in our case for several reasons. It required developing skills (programming, research, funding) that transferred well to the students' own fields of study (STEM). It naturally allowed for many sub-projects to be developed by using the code to examine various aspects of the pandemic. Finally, it also provided a way for students to gain a tangible grasp on the rapidly changing world around them.

USING KOLB'S LEARNING CYCLE TO IDENTIFY SLOS AND REPLICATE EXPERIENTIAL LEARNING [9]

- **Concrete Experience:** New members express interest and observe ongoing work.

- **Reflective Observation:** They determine how they can contribute and what they want to learn.
- **Abstract Conceptualization:** Members propose a sub-project they are passionate about and their ideas on how to implement it.
- **Active Experimentation:** They complete the work for their sub-project that aligns with their goals (ex. wanting to learn how to code so they choose a coding heavy project).

IDENTIFYING SOURCES OF FUNDING AND OPPORTUNITIES FOR DISSEMINATION

Students were prompted to seek funding to support the group with the idea of presenting at a conference or publishing in a journal. This provided students with meaningful opportunities to communicate their work as well as get hands-on experience with the realities of research funding. As noted earlier, students were quite successful and even obtained funding for stipends to work five hours per week.

FOSTERING INDEPENDENT RESEARCH IN A COLLABORATIVE ENVIRONMENT

We found that empowering students to lead sub-projects was important and allowed them to have a natural place in the group. Students were invited to present their work at weekly group meetings, and as it matured, they were then encouraged to present at undergraduate conferences. While providing research experience, this also provided ownership of a project and something that could be reflected in a reference letter.

ENCOURAGING LEADERSHIP, MENTORSHIP, AND INTER-DISCIPLINARITY

An important aspect of the group was the mentorship between students at different levels. Graduate students helped undergraduates, and upper year undergraduates acted as mentors to their lower-year counterparts. Students in life-sciences educated all of us on biology while learning to code in Python. The upper year undergraduates were encouraged to show leadership and seized the opportunity to organize weekly meetings, setting agendas, and milestones for publishing a paper.

CONCLUSION

Opportunities for undergraduate experiential learning in research are limited but can have significant positive impacts on student's careers. To address this gap, we presented a case study from an undergraduate-led research group at Queen's University in hopes that others may replicate and improve upon our experience.

ACKNOWLEDGEMENTS

We acknowledge the support of the Department of Physics, Engineering Physics & Astronomy at Queen's University through a research initiation grant, the Queen's University Arts and Science Research Fund, the Queen's University Bartlett Student Initiatives Fund, and the Natural Sciences and Engineering Research Council of Canada, funding reference number SAPIN-2017-00023.

Additionally, all of the individuals who were involved without whom this project would not have been possible: Mark R. Anderson, Irina Babayan, Charlotte Z. Reed, Mehdi Shafiee, Benjamin Tam, Tianai Ye, and others.

REFERENCES

[1] M. Healey and A. Jenkins, Developing undergraduate research and inquiry, The Higher Education Academy, June 2009.

[2] R.A. Katula and E. Threnhauser, Experiential education in the undergraduate curriculum, Commun. Educ. **48**, 238–255 (1999); doi: 10.1080/03634529909379172.

[3] National Research Council, Division on Engineering, Physical Sciences, Board on Physics, Committee on Undergraduate Physics Education Research, and Implementation, *Adapting to a Changing World: Challenges and Opportunities in Undergraduate Physics Education* (National Academies Press, Washington DC, 2013); doi: 10.17226/18312.

[4] P. Mulvey and J. Pold, Physics Bachelors’ Outcomes: Focus on Graduate School and the Effects of the Pandemic, Data from the Degree Recipient Follow-Up Survey for the Classes of 2019 and 2020, (American Institute of Physics, aip.org/statistics, 2023); doi: 10.1063/sr.63fabf38d4.

[5] M.C. Linn, E. Palmer, A. Baranger, E. Gerard, and E. Stone, Undergraduate research experiences: Impacts and opportunities, Science **347** (2015); doi: 10.1126/science.1261757.

[6] A.N. Micuda *et al.*, Exploring a targeted approach for public health capacity restrictions during COVID-19 using a new computational model, Infect. Dis. Model. **9**, 234–244 (2024); doi: 10.1016/j.idm.2024.01.001.

[7] F. Brauer and C. Castillo-Chavez, *Mathematical Models in Population Biology and Epidemiology*, 2nd ed., vol. 2 (Springer, New York NY, 2012).

[8] “QUABOOM,” 2023, *Github*. Accessed: Mar. 01, 2025. [Online]. Available: https://github.com/Queens-Physics/quaboom

[9] A.Y. Kolb and D.A. Kolb, Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education Experience-Based Learning Systems, Academy of Management Learning & Education **4**, 193-212 (2005); doi: 10.5465/amle.2005.17268566.