FEATURE ARTICLE

# Student Point of View: Living and Growing as Scientists – Doing the Process of Science during Distance Education

KAYLYNN IMSANDE, LUCY MCGUIRE, LUKE WHEELER

**Abstract**

*At a time when all course instruction had been moved online, it seemed wishful thinking for a group of undergraduate students to begin authentic, independent research. With curious, creative, and motivated mindsets; however, we learned not only that such research was possible during a global pandemic, but that it could provide vital learning opportunities in our careers as students and scientists. Guided by mentors of UW-Madison's honors biology Biocore program, we worked as a team of three undergraduate scientists and were given significant autonomy over all aspects of our research project. We planned, conducted, and communicated our science and here we provide a commentary of our learning throughout the process, as well as recommendations for instructors of other undergraduate science, technology, engineering, and math programs based on the factors that best facilitated our learning.*

**Key Words:** *undergraduate research; student perspective; remote research; research mentor recommendations; curriculum.*

## ○ Introduction

As aspiring scientists during a global pandemic in the academic year 2020–2021, our desire to conduct real research as undergraduates at first seemed unrealistic. We (K.I., L.M., and L.W.) soon learned that the designation of "real research" has little to do with extravagant equipment or the location of the research, but rather depends on the continuous development of knowledge about an experimental system and the in-depth analysis that cultivates this knowledge.

*Our experiences taught us that, despite limitations due to the pandemic and the confines of our homes, we could still apply the process of science (POS), iteratively and with high quality, to investigate our questions, maintain a research mindset, and perform authentic research. This editorial seeks to provide a unique commentary, from an undergraduate student perspective, on our journey through our independent research and learning through engaging in the POS.*

This understanding of research and science was a mindset we developed through our experience in an undergraduate biology curriculum at a large Midwest R1 university. The integrative four-semester lecture curriculum and course-based undergraduate research experience (CURE)-based (Corwin et al., 2015) laboratory course sequence focuses on guiding students' development of an inquiry and discovery-based mindset that encourages curiosity (Batzli 2005; Batzli et al., 2018 2022; Burgess 2002); Harris et al., 2018 This curricular approach is in alignment with the American Association for the Advancement of Science (AAAS) Vision and Change (2011) recommendations to improve the quality of undergraduate biology education through more comprehensive learning and the development of higher-level thinking skills (see Supplemental Material Table S1 available with the online version of this article).

When we first read the AAAS National Call for Vision and Change (2011), as students, we recognized the core competencies it stated as relevant to how scientists do science and as those we experienced in laboratory courses taken during the pandemic. From the start, we were empowered to be curious, dive deeply into primary literature, develop questions, and, essentially, to conduct our own research as principal investigators and collaborators. This continued even during a time when all research labs on campus had closed their doors to undergraduate students due to the COVID-19 global pandemic. The lack of opportunities in research labs at this time did not dampen our growing scientific curiosity but rather pushed us to explore creative options for conducting research in the given circumstances.

*The American Biology Teacher*, Vol. 85, No. 9, pp. 488–492, ISSN 0002-7685, electronic ISSN 1938-4211.  DOI: https://doi.org/10.1525/abt.2023.85.9.488.

Our experiences taught us that, despite limitations due to the pandemic and the confines of our homes, we could still apply the process of science (POS), iteratively and with high quality, to investigate our questions, maintain a research mindset, and perform authentic research. This editorial seeks to provide a unique commentary, from an undergraduate student perspective, on our journey through our independent research and learning through engaging in the POS. We also highlight insights from our experience and provide recommendations that may be valuable to undergraduate science, technology, engineering, and mathematics (STEM) instructors who provide authentic research opportunities for their students.

## ○ Context

The POS framework that our biology program uses to aid undergraduates in conducting research is designed to help students achieve the core competencies outlined in the National Call for Vision and Change. Batzli et al. (2022) present the POS as a cycle of benchmarks representing scientific research, with an emphasis on review and feedback from peers and mentors at every step. This process is cyclical and iterative, which distinguishes it from the more traditional "scientific method" model that we previously learned in science courses as a linear process with a beginning and an end and isolated steps along the way.

In fall 2020, as part of our first-semester biology lab, we engaged in our first POS cycle by conducting research projects from our apartments investigating environmental effects on a rapid cycling plant species, *Brassica rapa* (see POS Cycle #1 in Figure 1). This experience inspired us to pursue an "independent study," a mentor-facilitated collaborative research project conducted independently of a traditional lab course, through the spring of 2021, during the height of the COVID-19 pandemic. The timing and remote context of our research required great creativity and led to an array of adaptations and challenges that we overcame in order to work collaboratively as a team of researchers. This experience built our confidence as scientists and inspired our learning and appreciation of the scientific process.

We designed our independent study using conclusions and observations from our initial biology lab research on *B. rapa* and began this second cycle of the POS entirely remotely from our respective campus apartments, requiring flexibility and creativity in designing our experimental setup (POS Cycle #2 in Figure 1). The unique experimental setups resulting from nuanced differences in each of our apartments created difficulties in analyzing our compiled data. This challenge, however, presented us with an opportunity to consult with a biostatistician, who helped us configure an appropriate statistical setup for our experimental design.

We presented our study as an online research poster (available in the Supplemental Material Figure S1 online) at a virtual research conference (UW-Madison Undergraduate Research Symposium) in spring 2021, emphasizing that future research would need to be conducted to definitively address whether our independent variable was the force behind our results, as opposed to the differences in other confounding variables.

Because of uncertainties in our conclusion, a follow-up independent study was performed in summer 2021 to address confounding variables (see POS Cycle #3 in Figure 1). The unexpected results discovered through this POS Cycle #3 forced us to question our original rationale and provided the foundation for K.I. to pursue a senior thesis project in 2021–2022 when research resumed in person in a traditional laboratory setting (Imsande & Batzli, 2022). From this, we learned a valuable lesson in how science is conducted: as you learn and grow as a scientist and as new knowledge comes to light, you continually revise and question your understanding of things you thought you knew; you embrace discovery as well as uncertainty and ask new questions.

## ○ Outcomes

Figure 1 depicts a summary of learning outcome themes that resulted from the three POS cycles we experienced, the key mindsets we held as students and the key mindsets of our mentors.

The first outcome of this project was autonomy in our research. Due to the nature of independent research, there was much more freedom in designing our experiment than is typical in general lab courses. Meeting agendas, due dates, presentation times, and so forth were set by us as students and guided by the cyclic POS (including literature review, hypothesis development, experimental design, data analysis, etc.). With the lack of graded deadlines, our research was primarily motivated by intellectual curiosity rather than grades; this finding is similarly reported in Evans and Boucher's (2015) study on utilizing choice and autonomy to foster intrinsic motivation in students. Thus, we fully invested ourselves in our work rather than "dissociating," as one might do when conducting group work in an isolated virtual setting. The flexibility of our timeline also added freedom to our experimental design, allowing us to extend our research past the presentation of our initial results. By having this time to further investigate our initial results, we were able to consider in greater depth why we observed the results we did, leading us to design a supplementary study. Learning outcomes of autonomy, creativity/adaptivity, and confidence in research from our experience are similarly supported by Hanauer et al. (2017) and Forrester (2021). Ultimately, this autonomy and independence fostered a more complete understanding of our experimental system, while also increasing our engagement and learning throughout the process.

Another outcome was our realization of the universal accessibility of conducting research. Prior to this research project, authors had similar experiences in primary school of viewing images of scientists in lab coats with test tubes, leading them to make assumptions about who can do science and where it can be done. In this research project, we were able to design, carry out, and communicate our science from three isolated locations, using low-cost, relatively compact, and easily accessible, inexpensive research setups. From this experience, we learned firsthand that "scientist" does not just refer to those in white lab coats conducting experiments in expensive laboratories, but rather includes anyone performing scientific inquiry at any level, and in any location. Corwin et al.'s (2015) study on CUREs reached a similar conclusion, stating that:

> through immersion in the culture of science, students not only have opportunities to see science and scientific thinking in action but also to develop in terms of their scientific identity and sense of belonging to the broader scientific community.

A third outcome of this project was our newfound understanding that the POS does not have a definitive endpoint and there is no definitive right or wrong answer at the end of an experiment. We cycled through the POS multiple times throughout this study,

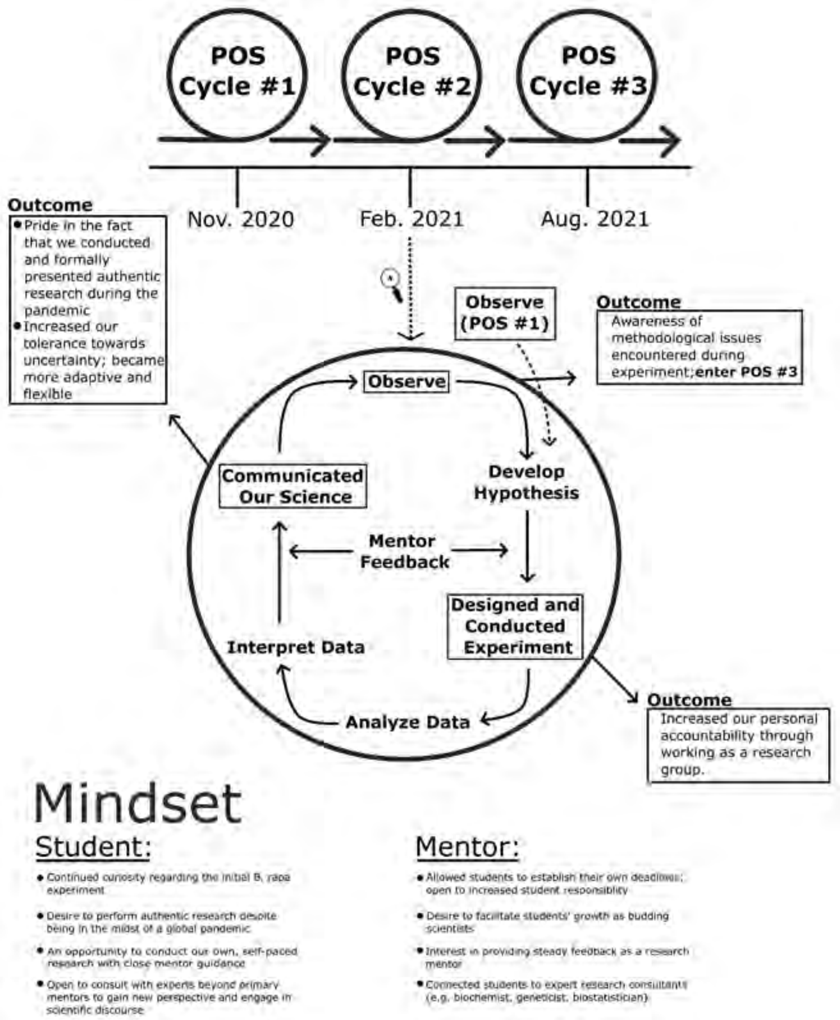


**Figure 1.** Overview of how POS Cycle #2 emerged from POS Cycle #1 and led into POS Cycle #3, resulting in (often unexpected) learning outcomes. Flexible mindsets from both students and instructors were key to our completion of three iterations of authentic scientific practice.

receiving frequent feedback, which encouraged us to reevaluate when an issue was identified. We came to understand analysis, feedback, and reevaluation as a natural progression that scientists constantly move through, and essential to the integrity of our science, rather than a failure in our system or our thinking. Scientific ideas are constantly evolving. Gaining new understanding is cause for celebration, not dismay at previous knowledge found to be "incorrect." Rather, conducting an experiment, making observations, and engaging in scientific discourse throughout leads to new questions, new research, and new knowledge (Imsande & Batzli, 2022). This iterative, cyclic POS that guides the curriculum we experienced and other CURE-based programs emphasize, as shown in figures 12.1 and 12.2 of Batzli et al. (2022), was an ideal framework and starting point for our independent research.

The structure of our study also allowed us to recognize the value of good research mentors. We worked closely with our mentors, meeting weekly, and allowing our mentors to help us develop our thinking and reasoning skills through discourse and feedback. Strategic questions posed by our mentors were designed to allow us to arrive at solutions without being given the answers, challenged our thinking, and furthered our intellectual growth as scientists. These qualities of a good mentor are similarly supported by Guston (1993), who writes that the ideal mentor challenges the mentee, without taking a position of superiority or limiting autonomy of the mentee(s). Our mentors' approach to guiding us, along with the iterative nature of our research, helped us build confidence in, ownership of, and identity with our science, and equity with our mentors (Batzli et al., 2022). In addition to our primary mentors, we had the opportunity to work with several experts who consulted on our study. One expert on *B. rapa* FastPlants specifically provided the valuable feedback on our research while also serving as an excellent example of an expert in the field conducting research in his own home instead of a "fancy" laboratory.

## ○ Recommendations

Based on our experience, we have included some recommendations that we believe will help future students and their mentors to develop students' research mindset and science identities (see Table 1). The general takeaway from our experiences and suggestions is the importance of allowing student research to be curiosity driven as much as possible, while encouraging communication and feedback between students and mentors frequently along the way.

**Table 1.** Recommendations for STEM lab courses focused on the process of science to promote a research mindset and science identity.

| Recommendations for Lab Courses | Affordance | Challenge | Suggestions for Instructors |
|---|---|---|---|
| Self-directed research | Increase student ownership of experiment and dedication to research. | With a large class, it is difficult to give students full freedom in their experimental system due to resource constraints. | Present a topic of research to students (e.g., animal physiology) and explain resources available but allow groups to independently generate a research question given logistical constraints. |
| Flexibility in schedule/deadlines | Make research curiosity driven rather than grade- or assignment driven, which increases student ownership and interest in the research. | For a lab course, deadlines/ assignments are important to keep students on track within a semester time frame and allow for student performance assessment throughout the course. | As a first assignment, ask teams to create a research schedule for instructor approval that will allow them to complete their research in the time allotted. This should include deadlines such as develop research question, begin data collection, and so forth. |
| Encourage feedback from peers, undergraduate TAs (uTAs), and instructors | Consistent feedback and questions from mentors cultivate a more complete understanding of the process of science at each step and develops students' reasoning skills, teaching students to think like scientists. | With a larger class size, it can be more difficult to have frequent and in-depth feedback meetings with each individual group, especially if each is doing different research. | Pair research groups together for regular feedback meetings for students to practice providing and receiving feedback (allowing instructor feedback meetings to happen less frequently). Incorporate uTAs (students who have taken the course previously) into courses to provide additional feedback. |
| Extension beyond initial POS | Facilitate a complete understanding of the experimental system by encouraging in-depth consideration of what the results mean, if they can be trusted, and how confidence can increase with additional research. | Within a stricter class schedule, time does not always allow for further development of research projects after initial conclusions. | If time does not allow for the continuation of student research, ask students to design and schedule out a follow-up experiment they would conduct if time permitted, and provide the opportunity for students to engage in independent research to carry out this experiment, if possible. |
| Research mentors | As with feedback, being in regular communication with mentors helps develop student thinking and scientific reasoning skills. | Larger class sizes can make student access to research mentors more difficult due to instructors having to split time between students. | Encourage students to reach out to expert scientists in their field of research and ask them to meet and discuss the experimental design they planned out, if scientists are willing. |
| Working as a team with joint interests. | Allows research tasks to be completed more efficiently and provides a source of constant peer feedback and discussion. Joint interest in our topic promoted equal contribution. | It may be difficult to successfully group students based on shared interests in a more general lab course. | Before assigning research groups, ask students to submit potential research questions they are interested in and make research groups based on these potential questions. Encourage communication among teammates. |

## ○ Conclusion

After completing three POS cycles of research and reflecting on the experience, we concluded that our student experiences, including successes, failures, and learning to troubleshoot through difficult challenges were all key components of "doing science."

We found that the most salient attributes of our experience to be our high level of autonomy in research and creativity working with our model systems, which bolstered our confidence and identity as true scientists. Additionally, through multiple iterations of the POS, we improved as scientists and grew our sense of belonging in the scientific community. Ultimately, we learned that science is incredibly accessible and can be done by anyone.

While our research was not groundbreaking, it reflected where we were intellectually and challenged us compared to previous laboratory experiences. Our year as scientists-at-home during the pandemic allowed us to grow as scientists, do authentic science, and confirmed that student-driven research can successfully be done remotely.

## ○ Acknowledgments

The authors would like to thank the following people for their contributions to and mentorship during our study: Janet Batzli and Michelle Harris (research mentors), Seth McGee (laboratory manager), Paul Williams (*Brassica rapa* Fast Plant creator and plant geneticist), and Erik Nordheim (biostatistician).

## References

American Association for the Advancement of Science. (2011). *Vision and Change in Undergraduate Biology Education: A Call to Action.*

Batzli, J. M. (2005). A unique approach? Four semesters of biology core curriculum. *CBE: Life Sciences Education*, *4*(2), 123–137.

Batzli, J. M., Harris, M. A., Lee, D., & Horn, H. A. (2022). Feedback and discourse as a critical skill for the development of experimentation competencies. In N. J. Pelaez, S. M. Gardner, & T. R. Anderson (Eds.), *Trends in Teaching Experimentation in the Life Sciences. Contributions From Biology Education Research* (pp. 243–262). Springer. https://doi.org/10.1007/978-3-030-98592-9_12

Batzli, J. M., Harris, M. A., & McGee, S. A. (2018). It takes time: Learning process of science through an integrative, multi-semester lab curriculum. In *Tested Studies for Laboratory Teaching: Proceedings of the Association for Biology Laboratory Education* (Vol. 39, pp. 1–8). Association for Biology Laboratory Education. https://biocore.wisc.edu/wp-content/uploads/sites/1035/2016/06/Batzli_Harris_McGee2018_ItTakesTime.pdf

Burgess, A. B. (2002). Cooperative learning: Moving from theory to practice in a class of 80 students. *Biocene*, *28*(3), 3–8.

Corwin, L. A., Graham, J. G., & Dolan, E. L. (2015). Modeling course-based undergraduate research experiences: An agenda for future research and evaluation. *CBE: Life Sciences Education*, *14*(1), es1. https://doi.org/10.1187/cbe.14-10-0167

Evans, M., & Boucher, A. (2015). Optimizing the power of choice: Supporting student autonomy to foster motivation and engagement in learning. *Mind, Brain, and Education*, *9*(2), 87–91. https://doi.org/10.1111/mbe.12073

Forrester, N. (2021). How the pandemic is reshaping undergraduate research. *Nature*. https://doi.org/10.1038/d41586-021-01209-2

Guston, D. H. (1993). Mentorship and the Research Training Experience. *Responsible Science: Ensuring the Integrity of the Research Process* (Vol. 2). National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK236193/

Hanauer, D. I., Graham, M. J., SEA-PHAGES, Betancur, L., Bobrownicki, A., Cresawn, S. G., Garlena, R. A., Jacobs-Sera, D., Kaufmann, N., Pope, W. H., Russell, D. A., Jacobs, W. R., Sivanathan, V., Asai, D. J., Hatfull, G. F., Actis, L., Adair, T., Adams, S., Alvey, R., & Zimmerman, A. (2017). An inclusive research education community (iREC): Impact of the SEA-PHAGES program on research outcomes and student learning. *Proceedings of the National Academy of Sciences USA*, *114*(51), 13531–13536. https://doi.org/10.1073/pnas.1718188115

Harris, M. A., Grange, S., Feeney, A. (2018). Undergraduate students are the key to community science outreach partnerships. Article 30 in: McMahon K, editor. Tested studies for laboratory teaching. Volume 39. Proceedings of the 38th Conference of the Association for Biology Laboratory Education (ABLE). http://www.ableweb.org/volumes/vol-39/?art=30

Imsande, K. G., & Batzli, J. M. (2022). Additional green light induces shade response symptoms in *Brassica rapa* as evidenced by increased lateral root spread. *microPublication Biology*. https://doi.org/10.17912/micropub.biology.000723

KAYLYNN IMSANDE (imsande@wisc.edu) is a research intern in the Department of Integrative Biology at the University of Wisconsin-Madison. LUCY McGUIRE (ltmcguire@wisc.edu) is a research intern in the Department of Integrative Biology at the University of Wisconsin-Madison. LUKE WHEELER (jlwheeler3@wisc.edu) is a research intern in the Department of Medicine/Geriatrics at the University of Wisconsin-Madison.