ILLUMINATIONS

Undergraduate research using single-subject research design in exercise physiology

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INTRODUCTION

Undergraduate research (UGR), particularly in the sciences, has been documented to be a high-impact educational practice that teaches a variety of disciplinary and transferable skills, as well as supports the personal and professional development of the undergraduate scientist (24). A variety of reports across many disciplines show that engaging in an UGR experience can enhance disciplinary skills, such as research design, data collection and analysis, information literacy, and scientific communication (22, 23, 32). Students, who conducted research as an undergraduate, also noted gains in a better understanding of the research process and clarification of their career path. UGR has also been shown to improve other more global transferable skills and habits, such as student self-confidence, tolerance for obstacles, and an ability to work independently (23). In addition, UGR experiences have been shown to be especially beneficial for underrepresented minority students and women (2, 12, 15, 20), as intensive UGR experiences help create strong mentoring relationships with more senior scientists and esprit de corps with others students that can offer needed support during challenging times (2, 12, 15). Collectively, UGR experiences promote retention in STEM fields and increase the likelihood that students will pursue a PhD (17).

Historically, these experiences have taken a variety of names, such as research internships, research apprenticeships, UGR experiences, or research experiences for undergraduates. Still, the challenges of traditional UGR experiences are that they serve so few students, are quite competitive to find, and require the devotion of extensive time, usually in summer or time outside of class. In response to these limitations and in an attempt to broaden UGR participation, many faculty members have begun using Course Based Undergraduate Research Experiences (CURE) (1, 6, 11) or inquiry-based laboratories (31). Both CURE and inquiry-based laboratories embed research in formal laboratory class, permitting a larger group of students to gain research experience. Although they share many similar features, CURE laboratories represent a more comprehensive model of inquiry-based laboratory experiences. In inquiry-based laboratories, students, mostly in groups, focus on smaller projects that last a few weeks, are centered around a single part of the research process, research question, or technique, and often culminate in a larger multiweek project to conclude the course (31, 36). The advantages of both inquiry-based and CURE experiences is that they require only one instructor, are open to any student who enrolls in the course, are conducted primarily during class time, and are typically carried out in a teaching laboratory, as opposed to specialized research spaced. Both CURE and inquiry laboratories were intended to replace traditional laboratory courses, also known as confirmation, verification, or “cookbook” laboratories (36). Both inquiry-based laboratories and CUREs have the potential to expand the number of students exposed to UGR in meaningful ways. Both also promote student engagement when students ask and answer their own questions, which also contributes to student engagement and persistence in science (19). Introductory level courses are also a great place for these experiences (7, 16), as they give students an early start on a potential research career (17, 19). Both CURE and inquiry-based laboratories show gains in self-confidence and problem solving and an ability to work independently, similar to those observed in singular research experiences (17, 34). Course-based and inquiry-based laboratories for UGR in physiology and exercise physiology have been reported in this journal and elsewhere (4, 5, 10, 13, 17, 25, 30, 31).

In many cases, CURE and inquiry-based laboratories often involve group projects rather than individually designed and carried out projects. While group work has been shown to positively affect student learning outcomes, such as collaboration, there remains the problem of the varying commitment that any given student will bring to the group (10, 28). For example, in group projects, the selection of the research question may not fully motivate each team member to the same degree. Another challenge with group projects is that students often divide tasks based on their strengths (project design, writing, data collection, computer work, etc.), often avoiding the more personally challenging tasks in which they do need experience. Moreover, one of the most persistent challenges in group work is for each group member to contribute his/her fair share of the time on task (10, 25). Project scheduling has also been noted as one of the consistent challenges of group work, as some students may work or not want to meet outside of “lab” time (10).

Thus the challenge was to balance the need for individual students to design and conduct meaningful research while avoiding the pitfalls of group work that may detract from student learning without losing the value of collaboration. For this experience, a single-subject research design was employ, where the individual participant is the unit of analysis (27). Single-subject research has been used extensively in the development of evidence-based practice in special education (18) and rehabilitation research (3). The purpose of single-subject
research is to document causal, or functional, relationships between independent and dependent variables (3, 18). In a clinical setting, the goal is to determine whether there is clinical relevance of a treatment rather than statistical significance. The most basic single-subject design employs a planned comparison in AB design, where “A” represents the baseline status, and “B” represents the intervention or treatment (27) effect.

Accordingly, the learning objectives for this assignment were consistent with other variations of UGR (31), namely, to deepen students’ understanding and application of the scientific method by designing an experiment, collecting and analyzing and interpreting the data, and reporting the results; and, in addition, similar to independent research, to further develop student problem-solving skills.

**Assignment.** This assignment was developed for an upper level Biology of Exercise course. Twenty-eight students in this three-credit lecture-only course had taken at least 1 yr of biology, 1 yr of chemistry, at least one course in human physiology, all with accompanying laboratories, and statistics. The students enrolled in the course were all pre-health science students with interests in medicine, physical and occupational therapy, nursing, and/or exercise science. Experimental design and inquiry-driven laboratories were threaded throughout several of their previous courses, including introductory biology and human physiology, in a manner similarly described by Rivers (31) and Luckie et al. (25). However, for the large majority of students, this project would be the first project in which they were solely responsible for all aspects of the research. An overview of this assignment was given to the students on the first lecture as follows.

While experimental research often focuses on outcomes that are generalizable to larger populations, often in medicine, sport, and rehabilitation we need to design for and find out what works for the single person/athlete. To that end, you will identify a health-, wellness-, or fitness-related goal that you would like to achieve. You will develop a sound scientific methodology outlined in a research proposal, carry out the proposed experiment (using yourself as the only subject), and report the results both orally and in writing. Experiments should be a minimum of 4 wk and no longer than 6 wk.

**Details.** Essentially, every student would develop their own research proposal using themselves as the single subject, carry out all of the activities, write up the research in a format that followed the *Journal of Applied Physiology*, and present their research to the class at the end of the semester. During the first week, students were given a timeline of when each component was due and given the limitation that they needed to be able to measure their outcomes without complicated or expensive laboratory instruments. The latter would reduce the time burden on the instructor and simplify the project for students. Within the first 10 days after the assignment was presented, students had to meet with the instructor personally to discuss the project and for the safety and feasibility of the project to be assessed within the time constraints of the semester. Once approved, each student wrote a research proposal that included an introduction, grounded in research, and a detailed research methodology. Students were then organized into groups of three for a peer review process. Each group member had to evaluate and provide detailed written feedback on the proposed experiment and methodology outlined by each of the other members in his/her group. To give helpful directions and to facilitate a more directed peer review process, students were asked to frame their reviews around these questions:

- What, if anything, did you find interesting about the research proposal?
- Was the proposal scientifically sound?
- What questions or concerns do you have about the specific research methodology? Do you believe the intervention/program will result in meaningful changes? If not, please state why.
- Does the proposal adequately control for the nontreatment factors, such as diet, sleep, etc., that could impact the study?
- And, summatively, do you believe you could carry out the experiment as written? If not, please state why.

Students were given 1 wk to review their peer’s proposal. Once comments were received, each student had 1 wk more to incorporate those comments into a final proposal. After final proposals were turned in, they needed instructor approval, mostly for safety reasons, before starting their project. Once instructor approval was given, typically no more than 3 days after their final proposal, students could begin their experiment.

To assess the readiness for the experiment, and before beginning their experiment, students completed a Physical Activity Readiness Questionnaire (PARQ) (https://store.csep.ca/pages/getactivequestionnaire). Since students were conducting this project on themselves, there was no requirement for institutional review board approval. Still, the PARQ activity was conducted along with a thorough discussion of the institutional review board, its processes, and the ethics of informed consent with human research subjects.

Once per week, before and during the experiments, students were organized into small groups in class to discuss their progress and the challenges of their projects. During the first weeks, students briefly outlined their projects, and the small group discussions were framed around two questions: What is going well with your project? and What challenges/hurdles/questions do you have about your project that you need assistance with? Questions and other common concerns raised in those small groups were highlighted during the ensuing all-class discussion. If a problem was not adequately resolved in the small group, the entire class was invited to assist each other in dealing with the challenges raised. In almost every case, another student offered a concrete suggestion to help resolve the issue. Thematically, the majority of the student proposals generally centered around four areas: strength training, endurance training, high-intensity interval training, and nutritional/dietary modifications, all of which could be measured with accessible tools, such as stopwatches, scales, goniometers, and skinfold calipers. The instructor ensured that students had access to these measurement tools at critical junctures during their project.

**Outcomes.** The quality of the original student proposals, before peer review, varied greatly. Student peer review has been shown to be an effective tool for improving students’ writing and thinking skills, and peer-reviewing others research proposals should have a similar effect (25, 26). The majority of the proposals were sound scientifically, but students proposed experiments that were quite unreasonable in length (8–10 wk)
What did you learn about yourself as a subject in a reflective writing piece (9)?

In addition to presenting their research to the class, each student had to write both a traditional research style manuscript and a separate guided reflective statement. In general, all students met or exceeded the learning goals outlined above and demonstrated sound understanding of applying the scientific method, coupled with moderate to strong scientific writing skills. As upper division biology students with many laboratory classes, they have had significant practice in generating research reports and papers, and, as a result, their research papers were generally well done, with no student earning lower than a B grade. Even without a formal statistical component (see below), most did an excellent job of analyzing and interpreting their data. They were all able to adequately identify both large and small factors that they believed influenced their results and were able to contextualize their results in light of previously published work. Considering our biology curriculum threads various aspects of UGR throughout its curriculum, this was a positive and affirming outcome.

Yet the most important piece of this assignment and their own learning was the reflective piece. Research shows that, when students stop and reflect metacognitively about what they know (or do not know) and what they have learned, they are able to identify gaps in their knowledge and skills and self-correct errors when appropriate (9, 29, 33, 35). To assist them in their reflection, which is not something science students typically do, they were given the following prompts for the reflective writing piece (9).

- What did you learn about yourself as a subject in an experiment?
- What did you learn from carrying out your project about scientific research?
- If you had to do it all over again, what would you do differently and why?

Students’ self-described learnings fell into categories outlined in the questions above: personal challenges in carrying out the project, the challenges of being a scientist, and what they would do differently.

**Personal challenges.** Ninety-five percent of the students thoroughly enjoyed the project and said they had felt highly motivated in part because they designed the project and because they would be working independently, without the inherent frustrations of group work. Only one student reported feeling ambivalent about the project, but he had an unrelated injury and was not able to complete it. The majority of students noted how hard it actually was to stay with the program they designed and to keep constant many of the control variables that they identified in their research proposals. They noted that exercising at the same time, eating a similar diet, and sleeping consistently were challenging guidelines to which to adhere. The majority who noted this had not really considered the fact that stress, unusual work and/or class schedules, and lack of sleep were factors that would distract them from their prescribed program. Several students, who had completed physical/occupational therapy internships, recognized that practical challenges of exercise prescriptions and that exercise/program adherence for clinical patients remains one of the persistent challenges for Physical Therapists.

**Scientific challenges.** The majority of the students indicated they initially felt confident and well prepared to design and carry out their research projects because of the group projects or inquiry-based laboratories completed in previous classes. Yet the biggest challenge they faced was working independently and not having a partner with whom they could share responsibilities. This challenge was ameliorated, for the most part, through the time devoted to weekly class discussions. In essence, those discussions functioned as group support, something that happens naturally during a group project, underscoring the value of collaboration in research. During the first week, the group of students conducting experiments on body composition realized that it would be virtually impossible for them to carry out skin fold tests with calipers on themselves, so they formed a small research group to measure skinfold on each other. Almost every student recognized the challenges of research, with the most common phrases being hard, challenging, or difficult. Every student noted the importance of keeping control variables constant and that this element was their biggest challenge. Several students wrote that, throughout the entire project, they kept identifying flaws in their research design, but noted they also were forced to become better at problem solving. These “manageable difficulties” yield problem-solving skills that are essential for students’ growth (8). Moreover, these transferable skills are difficult to teach in a traditional classroom setting, and only through unscripted and unique experiences, such as independent research, will students have a chance to learn them (24).

**Second time around.** Students were quite thoughtful and practical in their responses about how and what they would do differently. Many of the students indicated that, in the design phase, they would have tried to conduct a “micro” preexperiment to see if they could carry out the work. They also noted that writing about data collection as a theoretical exercise in their research proposals and actually collecting data are not the same thing. They noted that, in the design phase, they would have also liked to familiarize themselves with data collection devices, similar to what occurs in inquiry-based laboratories, before writing up their research methodology for the proposal. Control variables were also a common theme, as they became acutely aware that they did not realize how many different factors can influence research with humans. Finally, several students noted that, if given a second chance, they would have included more intermittent qualitative measures, such as stress level, mood, and or fatigue to assess how they were feeling during the experiment.

In terms of student learning, having students carry out this project proved to be a large success. From their research proposals and final papers, they clearly demonstrated a very good to excellent working knowledge of the scientific method, that they could plan and carry out a project, and that they were capable of advanced scientific thinking and analysis. From the reflective essays, it was clear that conducting the research independently helped them recognize the challenges of research and how they would think and plan differently in their next project.
Single-subject research experiences are not meant to replace inquiry-based laboratories or other UGR experiences. Rather, this particular variation builds on those prior experiences. As noted earlier, this was not the first research experience for these students. Each student had completed inquiry-based laboratories in their introductory courses and group research projects in their previous upper division courses. This variation provides an opportunity for more hands-on engagement and problem solving as the sole researcher and subject. Still, this project may not be the perfect or optimal UGR experience to teach all important aspects of research or for inexperienced students who may need more scaffolding that inquiry-based laboratories provide. Because there was only an “n” of 1, there was no statistical analysis. In a previous version of this course, student data were aggregated (and supplemented), and students did perform statistical analysis, but doing this did not seem to add anything new for them. Furthermore, some indicated that this depersonalized their project a bit. In this experience, the personal student growth observed from this independent project far outweighs the opportunities of having them work in groups and manage a larger project with a great number of subjects. Also, since many of the students are headed to careers in healthcare, where clinical significance is the goal (the treatment effect has a genuine, palpable, noticeable effect on daily life), this assignment fits well with their professional aspirations. In addition, the weekly discussions proved essential to help students practice and build on the collaboration skills learned through their previous inquiry-based laboratories or group projects. Moreover, it reinforced the value of discussion and collaboration, even though they were working independently.

In summary, exposing undergraduates to research, even experiments with a single subject, can yield quite positive results. The goal of this project was not necessarily intended to drive home key concepts in exercise physiology as others have done (4, 25, 30). Rather, in this case, students were encouraged to think and act like independent scientists, including working through all of the pitfalls of research, in planning and carrying out a project of their own design. An important, if not essential, part of this experience was the student’s own reflection about their experience and their ability to identify flaws and challenges in their original project and propose reasonable solutions. UGR can take a variety of forms and yield meaningful learning gains in students. While conducting single-subject research may not be standard practice in many science curricula, it can yield profitable learning gains and is consistent with what many of these students will do as healthcare professionals, which is design a program or treatment that will be about clinical significance for one of their future clients/patients.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

T.G.F. conceived and designed research; performed experiments; analyzed data; interpreted results of experiments; drafted manuscript; edited and revised manuscript; approved final version of manuscript.

REFERENCES

1. Auchincloss LC, Laursen SL, Branchaw JL, Eagan K, Graham M, Hanauer DI, Lawrie G, McLinn CM, Pelaez N, Rowland S, Towns M, Trautmann NM, Varma-Nelson P, Weston TJ, Dolan EL. Assessment of course-based undergraduate research experiences: a meeting report. Adv Physiol Educ 33: 29–40, 2010. doi:10.1152/advan.00025.2007.
2. Barlow AE, Villarejo M. Making a difference for minorities: evaluation of an educational enrichment program. J Res Sci Teach 41: 861–881, 2004. doi:10.1002/tea.20029.
3. Bohrovitz CD, Ottenbacher KJ. Comparison of visual inspection and statistical analysis of single-subject data in rehabilitation research. Am J Phys Med Rehabil 77: 94–102, 1998. doi:10.1097/00000206-199803000-00002.
4. Brown GA, Lynott F, Heelan KA. A fitness screening model for increasing fitness assessment and research experiences in undergraduate exercise science students. Adv Physiol Educ 32: 212–218, 2008. doi:10.1152/advan.00025.2007.
5. Casotti G, Rieser-Danner L, Knabb MT. Successful implementation of inquiry-based physiology laboratories in undergraduate major and nonmajor courses. Adv Physiol Educ 32: 286–296, 2008. doi:10.1152/advan.00000.2007.
6. Corwin LA, Graham MJ, Dolan EL. Modeling course-based undergraduate research experiences: an agenda for future research and evaluation. Adv Physiol Educ 14: es1, 2015. doi:10.1152/advan.00144.2005.
7. Dabney-Smith VL. A Multi-Level Case Study Analysis of Campus-based Male Initiatives, Programs, and Practices and the Impact of Participation on the Perceptions of First-year African American Male Community College Students in Texas (PhD thesis). Austin, TX: University of Texas, 2009, UMI no. 3378673.
8. Darling-Hammond L, Bransford J (Editors). Preparing Teachers for a Changing World: What Teachers Should Learn and Be Able to Do. New York: Wiley, 2007.
9. Davis EA. Scaffolding Students’ Reflection for Science Learning. Berkeley, CA: University of California, 1998, p. 1–340.
10. DiPasquale DM, Mason CL, Kolkhorst FW. Exercise in inquiry. J Coll Sci Teach 32: 388–393, 2003.
11. Dolan EL. Course-based Undergraduate Research Experiences: Current Knowledge and Future Directions. Washington, DC: National Research Council Commissioned Paper, 2016.
12. Eagan MK Jr, Sharkness J, Hurtado S, Mosqueda CM, Chang MJ. Engaging undergraduates in science research: not just about faculty willingness. Res High Educ 52: 151–177, 2011. doi:10.1007/s11162-010-9189-9.
13. FitzPatrick KA, Campisi J. A multiyear approach to student-driven investigations in exercise physiology. Adv Physiol Educ 33: 349–355, 2009. doi:10.1152/advan.00056.2009.
14. Gormally C, Brickman P, Hallar B, Armstrong N. Effects of inquiry-based learning on students’ science literacy skills and confidence. Int J Schola Teach Learn 3: 1–22, 2009. doi:10.20429/jstl.2009.030216.
15. Gregerman SR, Lerner JS, von Hippel W, Jonides J, Nagda BA. Undergraduate student-faculty research partnerships affect student retention. Rev High Educ 22: 55–72, 1998. doi:10.1353/hec.1998.0016.
16. Harrison M, Dunbar D, Ratmansky L, Boyd K, Lopatto D. Classroom-based science research at the introductory level: changes in career choices and attitude. CBE Life Sci Educ 10: 279–286, 2011. doi:10.1187/cbe.10-12-0151.
17. Hathaway RS, Nagda BAR, Gregerman SR. The relationship of undergraduate research participation to graduate and professional education pursuits: an empirical study. J Coll Student Dev 43: 614–631, 2002.
18. Horner RH, Carr EG, Halle J, McGee G, Odom S, Wolfe M. The use of single-subject research to identify evidence-based practice in special education. Except Child 71: 165–179, 2005. doi:10.1177/00440290507100203.
19. Hunter A, Laursen S, Seymour E. Becoming a scientist: the role of undergraduate research in students’ cognitive, personal, and professional development. Sci Educ 91: 76–74, 2007. doi:10.1002/sec.20173.
20. Jones MT, Barlow AE.L, Villarejo M. Importance of undergraduate research for minority persistence and achievement in biology. J Higher Educ 81: 82–115, 2010. doi:10.1080/00221546.2010.11778971.
21. Kolkhorst FW, Mason CL, DiPasquale DMP, Patterson P, Buono MJ. An inquiry-based learning model for an exercise physiology laboratory course. Adv Physiol Educ 25: 45–50, 2001. doi:10.1152/advances.2001.25.2.45.
22. Lopatto D. Survey of undergraduate research experiences (SURE): first findings. Cell Biol Educ 3: 270–277, 2004. doi:10.1187/cbe.04-07-0045.
23. Lopatto D. Undergraduate research as a catalyst for liberal learning. Peer Rev 8: 22–25, 2006.

Advances in Physiology Education · doi:10.1152/advan.00053.2019 · http://advan.physiology.org
24. Lopatto D. Undergraduate research as a high-impact student experience. *Peer Rev* 12: 27, 2010.

25. Luckie DB, Maleszewski JJ, Loznak SD, Krha M. Infusion of collaborative inquiry throughout a biology curriculum increases student learning: a four-year study of “Teams and Streams”. *Adv Physiol Educ* 28: 199–209, 2004. doi:10.1152/advan.00025.2004.

26. Lundstrom K, Baker W. To give is better than to receive: the benefits of peer review to the reviewer’s own writing. *J Second Lang Writ* 18: 30–43, 2009. doi:10.1016/j.jslw.2008.06.002.

27. Martella R, Nelson JR, Marchand-Martella N. *Research Methods: Learning to Become a Critical Research Consumer*. Boston, MA: Allyn & Bacon, 1999.

28. Myers SA, Smith NA, Eidsness MA, Bogdan LM, Zackery BA, Thompson MR, Schoo ME, Johnson AN. Dealing with slackers in college classroom work groups. *Coll Stud J* 43: 592–599, 2009.

29. National Research Council. *National Science Education Standards*. Washington, DC: National Academies Press, 1996.

30. Pearson RC, Crandall KJ, Dispennette K, Maples JM. Students’ perceptions of an applied research experience in an undergraduate exercise science course. *Int J Exerc Sci* 10: 926–941, 2017.

31. Rivers DB. Using a course-long theme for inquiry-based laboratories in a comparative physiology course. *Adv Physiol Educ* 26: 317–326, 2002. doi:10.1152/advan.00001.2002.

32. Russell SH, Hancock MP, McCullough J. The pipeline. Benefits of undergraduate research experiences. *Science* 316: 548–549, 2007. doi:10.1126/science.1140384.

33. Schraw G, Crippen KJ, Hartley K. Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Res Sci Educ* 36: 111–139, 2006. doi:10.1007/s11165-005-3917-8.

34. Shaffer CD, Alvarez C, Bailey C, Barnard D, Bhalla S, Chandrasekaran C, Chandrasekaran V, Chung HM, Dorer DR, Du C, Eckdahl TT, Poet JL, Frohlich D, Goodman AL, Gossler Y, Hauser C, Hoopes LL, Johnson D, Jones CJ, Kaehler M, Kokan N, Kopp OR, Kuleck GA, McNeil G, Moss R, Myka JL, Nagengast A, Morris R, Overvoorde PJ, Shoop E, Parrish S, Reed K, Regisford EG, Revie D, Rosenwald AG, Saville K, Schroeder S, Shaw M, Skuse G, Smith C, Smith M, Spana EP, Spratt M, Stamm J, Thompson JS, Wawersik M, Wilson BA, Youngblom J, Leung W, Buhler J, Mardis ER, Lopatto D, Elgin SC. The genomics education partnership: successful integration of research into laboratory classes at a diverse group of undergraduate institutions. *CBE Life Sci Educ* 9: 55–69, 2010. doi:10.1187/cbe.09-11-0087.

35. Tanner KD. Promoting student metacognition. *CBE Life Sci Educ* 11: 113–120, 2012. doi:10.1187/cbe.12-03-0033.

36. Weaver GC, Russell CB, Wink DJ. Inquiry-based and research-based laboratory pedagogies in undergraduate science. *Nat Chem Biol* 4: 577–580, 2008. doi:10.1038/nchembio1008-577.