Does it stick? A longitudinal study of introductory physics for life sciences at a small college

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At Swarthmore College, we began developing an Introductory Physics for Life Sciences (IPLS) course nearly 20 years ago. The electricity, magnetism and optics semester was launched in 2008 and both semesters have been offered regularly since Fall 2015. Two primary goals of this curriculum are (1) to prepare students to effectively use physical models and quantitative reasoning in biological and biomedical contexts, and (2) for students to come to view physics as relevant to the life sciences. To evaluate whether these goals are achieved, we conducted a longitudinal interdisciplinary study assessing students' abilities to use what they learned from IPLS in later biology and chemistry courses, as well as students' long-term attitudes toward physics. We found that IPLS students were more likely than non-IPLS students to reason quantitatively and mechanistically about particular biophysical phenomena, even up to two years after leaving the IPLS course, and were significantly more successful at building a physical model that combined ideas in a manner novel to them. We also found that positive changes in IPLS students' attitudes about the relevance of physics to the life sciences persisted for at least two years after the course ended. The specific methods and findings of this study have been reported elsewhere. In this paper, we describe how our IPLS curriculum leverages the rich network of interdepartmental faculty relationships at small institutions to support students to recognize the connections between physics and their other science classes, and describe how the opportunities for close relationships between students and faculty made possible a decade of research into the curriculum outcomes. By identifying and tracking student trajectories over time and across disciplines, we were able to identify student reasoning and attitudes that were specifically associated with prior or concurrent enrollment in IPLS.

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I. INTRODUCTION

We were honored by the opportunity to present at the 2024 Physics Education Research Conference, “Bridging the Institutional Gap: PER at Primarily Undergraduate Four-Year Institution, Two-Year College, and K-12 Levels.” We presented the work we’ve done over the last twelve years to assess student outcomes associated with Swarthmore’s introductory physics for the life sciences (IPLS) course [1-4] and, in hopes of contributing insights related to the conference theme, discussed the ways that this work has been either facilitated or hindered by our four-year small college environment. This PERC paper will focus on how our work was informed by the small-college environment, and will cite but not re-present published research results; those publications are all open-access.

Section II presents the Swarthmore context and the history of the course development; sections III and IV summarize the ways in which the context of a primarily undergraduate institution (PUI) facilitated or hindered our research into the attitudinal outcomes of the course (III) and into skill development (IV); and sections V and VI discuss broader implications and conclusions, respectively.

II. COURSE CONTEXT AND HISTORY

A. Swarthmore College context

One of the great joys of teaching at an undergraduate-only four-year college such as Swarthmore is the opportunity to work on research projects with undergraduates involved in a wide array of studies. Over the past 12 years, we worked with 18 undergraduates whose majors included physics, biology, math, educational studies, philosophy, and English. Currently three are high school teachers, one has a PhD in education, two are PhD candidates (one in physics education research and one in biophysics), one is in a master’s program for science writing, and the others are pursuing a wide variety of interests or are current students. We also had the opportunity to collaborate with colleagues in biology (Sara Hiebert Burch, an animal physiologist) and educational studies (K. Ann Renninger, an educational psychologist specializing in the study of interest and motivation).

Swarthmore College is a highly selective, all-undergraduate college, and enrolls roughly 1650 students. The student body is socioeconomically diverse, thanks to the need-blind admissions policy, and commitment to meet the full financial need of all admitted students without loans. Nearly a quarter of students are the first generation in their family to attend college; a slightly larger fraction pay less than 10% of the total cost of attendance. The majority of the other students are full-pay and come from families with significant educational and financial resources. This diversity is reflected in the IPLS classroom, as health professions attract students from a wide variety of backgrounds. At Swarthmore, the IPLS students are a more diverse group than those majoring in physics and astronomy.

B. Course development history

One of us (CHC) began the process of developing a calculus-based introductory physics for the life sciences (IPLS) course in 2006, facilitated by a 2005 presentation about the Bio 2010 report [5] to STEM faculty at Swarthmore. At the time, Swarthmore offered only a single calculus-based introductory physics course for all non-physics majors, with the first semester only offered in the fall and the second only in the spring. (A separate, more mathematically demanding three-semester sequence was taken by prospective majors). Consequently, offering IPLS required adding courses, rather than reforming an existing dedicated course for life science majors. Due to initial staffing limitations, from Spring 2008 through Spring 2015, only the second semester IPLS course (referred to here as IPLS 2) was offered; once its widespread benefits for students (as well as for the instructor) were established, and after the other author (BDG) joined Swarthmore and could share in teaching IPLS, the first semester (IPLS 1) was added in Fall 2015. IPLS 1 was initially offered only in odd years, until Fall 2020, and drew substantially on BDG’s graduate student experience with the NEXUS IPLS development at the University of Maryland [6-9].

Development of Swarthmore’s IPLS curriculum involved identifying and developing tasks centered around authentic [10] biological contexts, ones in which using physics to analyze that situation provided insight that a biology expert would recognize as meaningful. This work leveraged relationships among the faculty that were made possible by the small liberal arts college environment; with a total STEM faculty of only about 60, a group of 6 curricular development advisors from biology and biochemistry were able to give broad insight into the full academic trajectories followed by majors in their programs. These insights included specific ways that physics appears in those other curricula, down to the vocabulary and mathematical or graphical representations used in particular courses. The curriculum was then built using these contexts to motivate each topic.

Inspired by and extending the pedagogy of expansive framing [11-13], when particular biological or biochemical contexts occur in the IPLS courses, we make specific mention of the corresponding life science courses — e.g., “*For any of you who have taken or will take neurobiology, you will study this model of the neuron, which explains why active regeneration of the action potential along the neuron is needed.*” Our case study interviews, as well as informal interactions with students over years of teaching this curriculum, suggest that our calling attention to these Swarthmore-specific connections may have added salience and credibility for our students.

The overall choice of topics was guided by considering the areas that best connect to the local biology and biochemistry curriculum, as well as topics highlighted by professional societies [5, 14-15] and those needed to keep the physics presentation coherent. Development was also informed by the work of others in the emerging IPLS community [6, 16-20]. A detailed presentation of the early development process and Swarthmore's second semester IPLS curriculum is provided in Crouch and Heller [21].

III. INITIAL RESEARCH: INTEREST AND OTHER STUDENT ATTITUDES

The first in-depth evaluation of the Swarthmore IPLS course was launched when a rising senior (Panchompoo (Fai) Wisittanawat '13), a special major in physics and educational studies, approached CHC to ask about doing her senior research in physics education. Up until this point, due to the many demands on PUI faculty combined with the lack of graduate students, CHC had done little evaluation of the curriculum, although she had collected student responses on concept inventories and the CLASS survey [22]. Fai's interest led to a project jointly advised by K. Ann Renninger of the Educational Studies department; Ann is an educational psychologist whose research focuses on the development of interest and its role in learning. The details of this work are reported elsewhere [1]; here we note simply that this project was initiated around a student research project, and that the comparative evaluation of IPLS and non-IPLS student attitudes relied on the natural experiment of IPLS 2 being preceded by a standard first semester of introductory physics for four years. Due to the small size of classes at PUIs like Swarthmore, three years of data collection were required in order to tell a statistically meaningful story.

Fai's project focused on attitude and interest development during the IPLS year itself. We were also interested in whether the improvements in interest that we observed would endure after the course ended and we no longer had any input into the students' scientific experiences. As instructors, we had a handful of experiences in which former students sought us out to excitedly share their experiences encountering physics in their future research or studies, but we had not yet done any sort of research into the long-term effects of the course. A few years after completing the study with Fai, and as part of the longitudinal study described in the next section, we set out to investigate the long-term development of attitudes more systematically. We took advantage of the loyalty of Swarthmore students to send a follow-up survey a year after the IPLS course ended (at the suggestion of one of our advisory board members, Eric Kuo). In particular, we surveyed students specifically about their sense of the relevance and value of physics for understanding biology, using items developed by Kristi Hall and colleagues [23]. Gwen Rak '22 analyzed these responses and found that students' sense of the relevance of physics improved during the IPLS year, and this increased sense of relevance persisted a year later [4].

As part of our longitudinal assessment of IPLS student attitudes, we also conducted several sets of case-study interviews designed to help us better understand *how* the IPLS course supported students' interest development, a project that is still active today. The first set of findings, based on interviews carried out by Chandra Turpen, identified a set of "engagement pathways" by which students typically interact with the course material and develop interest. These pathways are reported elsewhere [2], and provide a framework for understanding how an IPLS curriculum can engage students with a wide range of academic interests and motivations. The loyalty of Swarthmore students was again essential for establishing these engagement pathways, as students frequently participated in a series of four interviews over the course of the academic year.

IV. RESEARCH INTO STUDENT SKILL DEVELOPMENT

One of the core goals of the IPLS course is to develop students' skills in quantitative reasoning and physical modeling of biological systems. In 2017, we undertook a longitudinal study to evaluate whether those student skills persisted past the end of the IPLS course. Initially, we sought to analyze student work on tasks assigned by faculty (without any input from the researchers) in later biology and biochemistry courses, in the hope that any differences observed between the work of IPLS and non-IPLS students would provide evidence of transfer. During these initial attempts, students were not explicitly asked to demonstrate their physical or quantitative reasoning; rather, we simply looked for evidence of such reasoning in student work on biology and chemistry tasks. Perhaps not surprisingly, these data proved inconclusive; there were hints that IPLS students exhibited more physical and quantitative reasoning than their non-IPLS peers, but few findings were statistically significant. It became clear that, to assess the degree to which IPLS students could use physical reasoning in later biology and chemistry coursework, tasks that probed these skills more directly were needed.

At the suggestion of Michelle Smith (Cornell University), we collaborated with one of our biology colleagues, Sara M. Hiebert, to develop a task for the biology capstone course which would assess students' quantitative reasoning skills as well as their ability to use physics ideas learned in the IPLS course. This study [3] took advantage of the Biology department not requiring its majors to take physics, but instead requiring them to take two courses from a list of courses in the science division which were considered to develop "quantitative reasoning and skills." We framed the task for students as a tool for the Biology department to assess students' learning from these quantitative courses. With this additional framing, we were able to instruct students to draw on any knowledge and skills they had developed in their study of science and math at Swarthmore, without specifically referring to physics in the task or instructions.

The task asked students to analyze and represent graphically the concentration gradient of fatty acids through the cells lining the small intestine using the ideas of diffusion, a concept taught heuristically in introductory biology and frequently referred to throughout the biology and biochemistry curriculum, as well as being taught mechanistically in IPLS 1. The context of animal digestion was chosen because no student would have previously studied it in any biology or IPLS courses. Written work from students in two successive offerings of the biology capstone was analyzed for evidence of skills in physical modeling, quantitative reasoning, and use and interpretation of graphical representation of quantitative data.

The findings of this study were reported by Geller, Rubien, et al [3]. Briefly, we found that students who had taken IPLS 1 demonstrated significantly greater success describing and leveraging the physical ideas associated with diffusion, even two or more years after taking the IPLS 1 course. Furthermore, students who had taken either IPLS course displayed more general quantitative skill and ability to use and graphical representations than those who had not, and two semesters of IPLS were associated with more skill than just one semester. We also confirmed that, as measured by GPA in all STEM courses, the students who had taken IPLS were not more successful STEM students overall. We concluded that the IPLS curriculum succeeded in supporting the development of these skills in an enduring manner.

Our longitudinal study leveraged a close collaboration with the Biology department, which was made possible by trusting relationships cultivated during the development of the IPLS curriculum; we were also able to serve the biology department, because our work was used to meet their institutional assessment requirement for that year.

V. BROADER IMPLICATIONS

Our study of student skill development benefited from collaborative relationships among science faculty. The ethos of the faculty community at a PUI can promote such collegial relationships apart from academic projects, particularly when faculty are neighbors as well as colleagues. In our experience, the opportunity that colleagues had to advise the development of the IPLS course strengthened many of those relationships beyond what would have arisen independently. These relationships subsequently undergirded work co-led by CHC and two biology colleagues, Kathy Siwicki (a neurobiologist) and Liz Vallen (a cell biologist) to launch the STEM Inclusive Excellence efforts at Swarthmore, aimed at sharing resources and strategies among Swarthmore's STEM faculty to better support the increasingly diverse student population. Several faculty involved in IPLS also collaborated to teach in the Swarthmore's Summer Scholars Program, a pre-orientation program supporting the transition to college for low-income and first-generation students. Finally, these relationships also launched mentoring relationships supporting new STEM faculty in more inclusive and interactive teaching. Overall, the collaboration supporting IPLS development also supported many later collaborations that benefited STEM students and faculty. We believe that this happened because of the respect communicated via the invitation to other faculty to have input into our curriculum, and because we engaged in stimulating, satisfying conversations about teaching that led to meaningful outcomes [16, 24].

Finally, we want to emphasize that this IPLS project benefited Swarthmore College as a whole. From before this project began until 2017, a broad array of initiatives in Swarthmore's science division were funded by the Howard Hughes Medical Institute, through their institutional Science Education grant program. Including IPLS curriculum development and assessment among those initiatives provided funding that supported BDG's initial position at the college, and also met an important College need to report substantial innovation and assessment to HHMI. We encourage PER practitioners at two- and four-year PUIs to investigate opportunities for synergy with institutional projects that could provide resources for PER and raise its profile at the institution.

VI. CONCLUSIONS

The work discussed here represents over a decade of work assessing introductory physics for life sciences at Swarthmore College. We have sought to highlight the ways in which this work was shaped by Swarthmore being an undergraduate-only four-year college. First, our work leveraged the strong relationships between faculty and students, and among faculty across departments, that are facilitated by the small community ethos. Second, at PUIs and similar institutions with heavier teaching loads that place a high value on teaching, curriculum development and PER can be synergistic; close interactions with students in relatively small classes can both speed the iterative process of improving curriculum, and contribute meaningful insights into how curriculum accomplishes its outcomes. We hope this story can serve as an example of the kind of work that can be done at such institutions, and can encourage and provide ideas to other PER practitioners in similar settings.

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[1] C. H. Crouch, P. Wisittanawat, M. Cai, and K. A. Renninger, "Life science students' attitudes, interest, and performance in introductory physics for life sciences: An exploratory study," *Phys. Rev. Phys. Educ. Res.*, vol. 14, no. 1, p. 010111, Mar. 2018, doi: 10.1103/PhysRevPhysEducRes.14.010111.

[2] B. D. Geller, C. Turpen, and C. H. Crouch, "Sources of student engagement in Introductory Physics for Life Sciences," *Phys. Rev. Phys. Educ. Res.*, vol. 14, no. 1, p. 010118, Apr. 2018, doi: 10.1103/PhysRevPhysEducRes.14.010118.

[3] B. D. Geller, J. Rubien, S. Burch, and C. H. Crouch, "Assessing the impact of introductory physics for the life sciences in a senior biology capstone course," *Phys. Rev. Phys. Educ. Res.*, vol. 18, p. 010120, 2022.

[4] G. Rak, B. D. Geller, and C. H. Crouch, "Assessing the Lasting Impact of IPLS on Student Interdisciplinary Attitudes," presented at the Physics Education Research Conference, 2020.

[5] National Research Council, *BIO2010: Transforming Undergraduate Education for Future Research Biologists*. Washington, DC: The National Academies Press, 2003. doi: 10.17226/10497.

[6] E. F. Redish *et al.*, "NEXUS/Physics: An interdisciplinary repurposing of physics for biologists," *Am. J. Phys.*, vol. 82, no. 5, pp. 368–377, May 2014, doi: 10.1119/1.4870386.

[7] B. D. Geller, B. W. Dreyfus, J. Gouvea, V. Sawtelle, C. Turpen, and E. F. Redish, "Entropy and spontaneity in an introductory physics course for life science students," *Am. J. Phys.*, vol. 82, no. 5, pp. 394–402, May 2014, doi: 10.1119/1.4870389.

[8] B. D. Geller, J. S. Gouvea, V. Sawtelle, and C. Turpen, "Sources of Affect around Interdisciplinary Sense Making," Jun. 2014, Accessed: Jun. 28, 2021. [Online]. Available: https://repository.isls.org//handle/1/951

[9] J. S. Gouvea, V. Sawtelle, B. D. Geller, and C. Turpen, "A Framework for Analyzing Interdisciplinary Tasks: Implications for Student Learning and Curricular Design," *CBE—Life Sci. Educ.*, vol. 12, no. 2, pp. 187–205, Jun. 2013, doi: 10.1187/cbe.12-08-0135.

[10] J. Watkins, J. E. Coffey, E. F. Redish, and T. J. Cooke, "Disciplinary authenticity: Enriching the reforms of introductory physics courses for life-science students," *Phys. Rev. Spec. Top. - Phys. Educ. Res.*, vol. 8, no. 1, p. 010112, Apr. 2012, doi: 10.1103/PhysRevSTPER.8.010112.

[11] R. A. Engle, P. D. Nguyen, and A. Mendelson, "The influence of framing on transfer: Initial evidence from a tutoring experiment.," *Instr. Sci.*, vol. 39, no. 5, pp. 603–628, 2011, doi: 10.1007/s11251-010-9145-2.

[12] R. A. Engle, "Framing Interactions to Foster Generative Learning: A Situative Explanation of Transfer in a Community of Learners Classroom.," *J. Learn. Sci.*, vol. 15, no. 4, pp. 451–498, 2006, doi: 10.1207/s15327809jls1504_2.

[13] R. A. Engle, D. P. Lam, X. S. Meyer, and S. E. Nix, "How Does Expansive Framing Promote Transfer? Several Proposed Explanations and a Research Agenda for Investigating Them," *Educ. Psychol.*, vol. 47, no. 3, pp. 215–231, Jul. 2012, doi: 10.1080/00461520.2012.695678.

[14] American Association of Medical Colleges-Howard Hughes Medical Institute Committee, "Scientific Foundations for Future Physicians," American Association of Medical Colleges, 2009.

[15] American Association for the Advancement of Science, "Vision and Change in Undergraduate Biology Education," 2009.

[16] D. C. Meredith and J. Bolker, "Rounding off the cow: Challenges and successes in an interdisciplinary physics course for life science students," *Am. J. Phys.*, vol. 80, pp. 913–922, 2012.

[17] D. C. Meredith and E. F. Redish, "Reinventing physics for life-sciences majors," *Phys. Today*, vol. 66, no. 7, pp. 38–43, Jul. 2013, doi: 10.1063/PT.3.2046.

[18] R. Hilborn, J. Burciaga, D. Meredith, M. Reeves, and P. Soto, *Conference on Introductory Physics for the Life Sciences Report*. American Association of Physics Teachers, 2014.

[19] C. H. Crouch, R. Hilborn, S. A. Kane, T. McKay, and M. Reeves, "Physics for Future Physicians and Life Scientists: a moment of opportunity," *APS News*, Mar. 2010. Accessed: Jun. 28, 2021. [Online]. Available: http://www.aps.org/publications/apsnews/201003/backpage.cfm

[20] R. Hilborn, "Physics and the revised medical college admission test," *Am. J. Phys.*, vol. 82, no. 5, pp. 828–833, 2014.

[21] C. H. Crouch and K. Heller, "Introductory physics in biological context: An approach to improve introductory physics for life science students," *Am. J. Phys.*, vol. 82, no. 5, pp. 378–386, May 2014, doi: 10.1119/1.4870079.

[22] W. K. Adams, K. K. Perkins, N. S. Podolefsky, M. Dubson, N. D. Finkelstein, and C. E. Wieman, "New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey," *Phys. Rev. Spec. Top. - Phys. Educ. Res.*, vol. 2, no. 1, p. 010101, Jan. 2006, doi: 10.1103/PhysRevSTPER.2.010101.

[23] K. L. Hall, "Examining the Effects of Students' Classroom Expectations on Undergraduate Biology Course Reform," University of Maryland, College Park, 2013. Accessed: Jun. 28, 2021. [Online]. Available: https://drum.lib.umd.edu/handle/1903/14080

[24] E. F. Redish and T. J. Cooke, "Learning Each Other's Ropes: Negotiating Interdisciplinary Authenticity," *CBE Life Sci. Educ.*, vol. 12, no. 2, pp. 175–186, 2013, doi: 10.1187/cbe.12-09-0147.