Investigating Perceptions of Relevance Towards Computation in an Introductory Physics for Life Science Course

Jacob Watkins[a], Nikolay Ivanov[b], Katie Hinko[a,c], and Kirtimaan Mohan[a,c]
a *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, U.S.A.*
b *Department of Computer Science and Engineering, Michigan State University, East Lansing, MI 48824, U.S.A. and*
c *Lyman Briggs College, Michigan State University, East Lansing, MI 48824, U.S.A.*

Computational modeling is by now a central pillar of modern science, yet it remains underrepresented in most introductory physics curricula at the post-secondary level. Recently, physics departments have begun incorporating computation into introductory physics courses, including those designed for life science majors. Such students form a significant proportion of enrollees in introductory physics courses, and will enter a technological world in which computational thinking is increasingly valuable. In this exploratory and qualitative study, we investigate how students connect to, and perceive the relevance of, computational activities built into an introductory physics for life sciences course. We use an ecological systems framework to understand and investigate relevance. We categorize the different ways in which students do and do not perceive the relevance of computational modeling in our physics curriculum. Our findings point to choices in course design that may increase relevance of computation for life science students, and indicate what mechanisms affect students' perceptions of computational curriculum in these settings. In doing so, we begin to build a picture of how to incorporate computation into introductory physics courses.

2023 PERC Proceedings edited by Jones, Ryan, and Pawl; Peer-reviewed, doi.org/10.1119/perc.2023.pr.Watkins

I. INTRODUCTION

Calls to reform science education underscore the need to adapt undergraduate physics education to a changing world, focusing on present challenges and future opportunities [1]. This reform emphasizes transforming STEM learning and strengthening discipline-based education research by stressing the importance of a curriculum that not only promotes understanding of fundamental principles, but also equips students with practical skills applicable to their careers [2, 3].

The rising interest in blending computational modeling and Computational Thinking (CT) into science and engineering curricula is underscored by a growing body of scholarly research. Work by Chabay et al. [4] discusses the benefits and challenges of integrating computational material into an introductory, calculus-based physics course. Aiken et al. [5] investigate high school students' understanding of CT and computational modeling on writing assignments and programming activities. More recently, Orban et al. [6] explored the meaning of CT in the setting of introductory physics, and Weller et al. [7] develop a learning goal framework for CT in computationally integrated physics classrooms. These efforts highlight the need to better align STEM education with STEM practice, which already incorporates computation to a substantial degree, and to help students thrive in an increasingly technological world.

While these considerations are in many ways top-down, driven by instructors, administrators, and policy makers, it is important that students see the new computational content as relevant to their lives. This is a two-way street, and while students are often faulted for "not seeing the relevance," instructors should nurture environments which invite the student to consider connections to their lives [8]. Work by Walkington and Sherman [9] indicates that personalizing learning activities according to "interests and experiences" improved performance in an Algebra 1 course, and a more recent work by McBride [10] explores customization in the context of physics for nonmajors. Lunk and Beichner [11] probed student attitudes towards computational modeling using spreadsheets in an introductory physics for life science (IPLS) course; however, there are limitations in the ability of attitudinal studies to probe relevance [8].

Our research addresses the following questions. What are the ways in which students find computational modeling relevant in an IPLS course? Further, is it possible to understand the sources and mechanisms of this perceived relevance in an Ecological Systems [12] (ES) framework? To answer these questions, we investigate student responses to computational modeling within the context of a studio-style course in introductory mechanics. We use an ES framework in our methodology and data analysis to probe, evaluate and identify themes around students' perceptions of relevance. With insight from this research, we hope to inform curriculum design that makes computational modeling more relevant for students not only as a skill, but also as a tool for learning.

II. RESEARCH CONTEXT

The setting of our study is the first semester of a sequence of IPLS Studio [13] courses that follow the Modeling curriculum [14]. Students are typically in their second and third years of undergraduate study, and are overwhelmingly ($\sim$80%) concentrated in life science majors. In surveys given at the beginning of the course, more than half ($\sim$56%) of students report post-graduation plans involving medical, veterinary, dental, or optometry school, and another fifth ($\sim$20%) plan on graduate studies in life sciences.

The course is run in a "studio-style" where lecture and lab are combined into one interactive class session. In a typical semester, 48 students are enrolled per section, with 4 sections running concurrently. Within each section, students sit at tables in groups of 5-6. Collaboration is embedded throughout the course curriculum, including the computational modeling activities investigated in this study. Students can request frequent help from the instructional team, which includes several faculty and graduate teaching assistants, along with 8–10 undergraduate learning assistants.

Computational modeling using VPython [15, 16] in Glowscript [17], was incorporated into the curriculum through pre-recorded videos, five in-class group activities, homework problems, and several exam questions. No prior coding experience was assumed as most students reported never having seen code before. The in-class activities were dispersed throughout the semester, and though they were done in groups, each student worked on their own copy of code. Most of the activities involved modeling systems of both physical and biological significance. Students are given minimally working programs [7, 18] and asked to fix code to produce the desired results or tinker with the parameters. The first code, in week two of the course, asked students to move a ball with a constant velocity and then give that ball an acceleration. In week five of the course, students were asked to consider a model of ligand-enzyme interactions in terms of elastic and inelastic collisions. In week eight, students modeled paramecium motion and dissipative forces. In week eleven, students simulated bound states of molecules. Finally, in the thirteenth and final week of class, entropy and diffusion were discussed in the context of modeling ideal gases.

III. THEORETICAL FRAMEWORK

Relevance is a notoriously difficult concept to define in an educational context, especially in a way that does not diminish the student's opinion and perspective. For an object, idea, etc. to be relevant to a student, it seems necessary that the entity links strongly with other aspects of the student's life. This suggests a network representation of relevance, whereby an entity is relevant if students report many strong connections to other facets of their environment. These facets may include familial relationships, classes, clubs and organizations, career trajectories, and broad societal norms and expectations.

The sheer number of facets of a student's environment necessitates an organizing principle. Thus, we augment our network-theoretic conception with an implementation of Bronfenbrenner's ES framework [12], which was originally

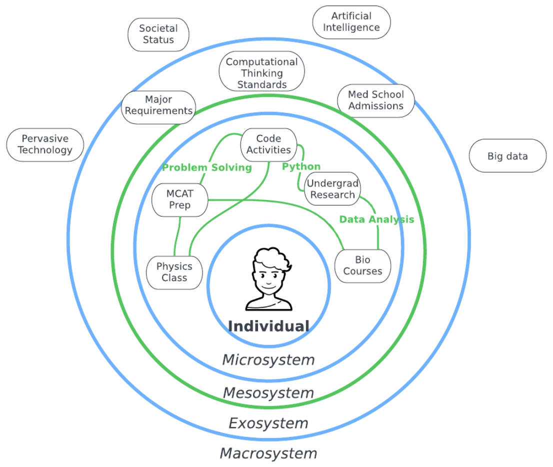

FIG. 1. Schematic of Ecological Systems (ES) framework for a hypothetical student in our study. Connections between facets of the Microsystem, shown as green curves, constitute the Mesosystem and are an indicator for relevance. This student finds the coding activities helpful for MCAT preparation, understanding physics, and Python skills for undergraduate research, but not biology classes. Relevance can also come from influences from the Exo- and Macrosystems.

adapted for relevance in introductory physics by Sawtelle and Nair [8]. Figure 1 gives a schematic depiction of this framework for a hypothetical student. In the ES framework, a student's environment is characterized by a series of nested layers, or "systems", with the individual at the center. Systems which are closer to the student are perceived as directly influencing, and being influenced by, the student. For operational clarity, we define the following systems in our study:

- The **Microsystem** comprises the most direct aspect of a student's environment. This may include a student's classes, friendships, and extracurricular activities.
- The **Mesosystem** is defined explicitly as connections within the Microsystem.
- The **Exosystem** is outside of a student's direct experience but not an overarching societal level. For example, while a student's MCAT preparation activities will fall in the Microsystem, the existence of the MCAT and other medical school admissions requirements are categorized into the Exosystem. Items in the Exosystem are relatively beyond the control of the student.
- For our study, the **Macrosystem** is the largest possible layer and consists of entities at the large-scale societal or cultural level. For example, all of our students exist in a context with growing influence of big data and artificial intelligence. Broad economic trends towards information technologies may influence students' choices and perceptions as well.

We do not consider the often-included "Chronosystem," or broad changes over time, because of the relatively short frame of time in which our study takes place.

IV. METHODS

Our study design is primarily qualitative, with the goal of uncovering themes from students' experience. We view this as a necessary step for a more in-depth or quantitative study.

The data of our study is as follows. We created pre- and post-course surveys and journal reflections given after in-class computational modeling activities to students in two sections of the course. Pre- and post-course surveys were obtained from 120 students and contained open- and closed-ended questions, including duplicate Likert scale prompts designed to gauge change over the course. Journal reflections, similar to the surveys, contained a mix of open- and closed-ended questions, and occurred during the course. We also conducted semi-structured interviews with three students near the end of the course. These interviews were approximately 30–40 minutes in duration and conducted over video calls.

We used the ES framework as a guide to probe relevance and its "source," e.g., the usefulness of computational modeling for a student's career, major, physics, or everyday life. For instance, consider a prompt taken from a journal reflection activity following the moving ball activity of week two.

> "Think of another situation where you might be able to build a computational model. This can be an everyday situation, or something related to another class. Describe that situation. Would computational modelling be useful, or would it be unnecessary in this situation – in what ways?"

Here, we are probing relevance of computational modeling to a student's "everyday situation," which in our framework lies in the Microsystem. Similar prompts were given to probe relevance to other aspects of a student's life, such as school or career, and the ES framework served to categorize them. We adopt a strategy employed in prior work [8] and avoid using the word "relevance" directly, since prior work has indicated that terms like "useful," "valuable," and "helpful" are more effective at probing relevance in written or verbal prompts. Similarly, we developed prompts using this approach for surveys and interviews.

After the end of the semester, all data were coded for emergent themes, performed independently by two of the authors (Watkins & Ivanov). Keeping the research questions and ES framework in mind, many of our codes take the form "computation's relevance to ..." which signifies a connection a student makes between computation and a facet of their life. After a first round of coding, all authors met to discuss and compare the two sets of codes and categorization schemes. Not all codes and categories were considered relevant to the present study, and the authors collectively trimmed the list of categories from each code set. Of those remaining, there was general agreement between the two sets, and alignment with the research questions and theoretical framework. Using their respective sets of codes, the two authors performed a second, more thorough round of coding with emphasis on the most relevant categories to the study. QualCoder, an open source software, was used for the analysis [19].

V. FINDINGS

Our data provide snapshots of students' attitudes and sense of relevance at different points in the course. We organize our findings according to major themes.

A. Initial Attitudes and Perceptions of Relevance

a. ***Students have inexperience and anxiety towards computation, yet some have determination to succeed.*** Naturally, students came into the course with a variety of perspectives towards coding, and these are reflected in the pre-course survey. While 66% of students report no prior coding experience, 84% report using computers to plot, model, or analyze data (data analysis will be a recurring theme in students' reflections on computers). When students were asked how much "anxiety do you feel about computer programming" in the course, 54% of students reported at least a moderate degree of anxiety (more precisely, these students gave a score of at least 60 out of 100, with 100 being most anxious). Notably, the distribution is bimodal, with 17.5% of students expressing almost no anxiety (defined as a score of less than 10 out of 100). One student wrote that *"The most challenging part I believe will be the coding aspect when we get to that. I have zero exposure to coding so it will be completely new and is intimidating."* It was interesting to see a small population of students, who were anxious, also expressed determination. One student wrote *"I sadly have never programmed before, but I'm hoping to catch on quickly and I'm excited to try."* In the ES framework, such students do not have computation in their Micro- or Mesosystems and further investigation is needed to understand the source of this attitude. One possibility, which we remark on at the end of this section, is the influence of the Macro- and Exosystems.

b. ***Computers are relevant for data analysis and visualization.*** When students were asked "what role computers play" in "doing science in your major, area of interest, or future career," most students reported some role rather than none, and their answers fell into natural clusters. The most salient clusters of responses were about data analysis, statistical modeling, and visualization. One author, in their parsing of student responses, recorded at least 31 distinct references to "data analysis" among study participants, without attempting a comprehensive count and classification, and was generally surprised by the consistency of these responses across different students. Indeed, this author had nearly four times as many coded texts for "data analysis" and "visualization" as for "simulations and modeling." Connecting this to the CT practices outlined in [6], the students appear to be deriving relevance primarily from data analysis. Our observations align with the students' stated background in programming (of those who have any). These students reported taking courses, previous or concurrently, by names like "Statistics for Scientists," which are required courses for many life science majors and use Rstudio. They were already introduced to some form of coding and computational modeling, but specifically for data analysis, and have thus formed such connections in their Mesosystem.

c. ***Computers are relevant because they are everywhere.*** Besides data applications, other students pointed to the general trend of increased technological penetration into our society (*"Everything we do now involves computers,"* one student writes). In the ES framework, we believe this to be in part due to the influence that the Macro- and Exosystems have on students attitudes towards technology and computers. For example, some students see computers as a valuable tool in the doctor's office, through charting, medical scanning, or communicating. At this point, we had not asked about the role of coding specifically, but do in end of course surveys.

d. ***Possible influence of the Macro- and Exosystem.*** It is interesting to comment on the possible influence of the Macro- and Exosystems on students' attitudes and perceptions of relevance of computation. First, in the absence of computation in the Micro- and Mesosystems, we still had a handful of students who seemed determined and excited at the prospect of computation. Further, the two kinds of responses we found and described above, namely the data-centric and the omnipresence of computers, can also be understood in the current societal context in which big data and artificial intelligence are currently having a substantial impact on peoples' lives — one student wrote *"check out chatGPT"* when asked to share final thoughts on coding experiences in class.

B. End of Course

a. ***Computational modeling is useful for learning how to code and to visualize but not useful for learning physics.*** At the end of the course, not all students found computation relevant to physics, even if they found the activities enjoyable or useful in other respects — *"I love coding and learned a lot but it didn't help with my understanding in physics."* Although this student reported writing "simple" code prior to the course, and therefore already has an atypical amount of coding experience relative to our population, many other students who didn't see a connection to physics managed to draw relevance — *"This code was useful in understanding how coding works, but I did not find it useful for physics".* The interviews shed more light on why many students found learning how to code more relevant than using it to learn physics. One student mentioned that she was simultaneously taking a data analysis class and a computational modeling class, both requirements for her biochemistry major. She felt that the kinds of coding done in each class were "significantly different," yet she said it was nice to see all the different languages and styles. Despite these differences, *"I definitely think taking them simultaneously helped kind of learn the codes and learn how to use the programs at the same time."* While she found examples towards the end of class, involving thermodynamics concepts such as enthalpy and entropy, helpful and interesting, she ultimately *"didn't really see the relevance"* of the coding to her physics learning. However, without the basics she learned here, she said *"I totally would be I'd be lost [sic.] in the rest of my [computational] modeling classes."*

Thus, in the ES framework, it appears that the link between physics and coding is weak for many students, while for a few students, coding remains strongly connected via other nodes such as their major. Further, we observed that students who saw visualization as the primary use of computational modeling activities found it less relevant for learning physics - *"For me [coding in the collision activity] was not very useful, I had a very similar idea when looking at the drawn model, but I can see how it could help some[one] visualize."*

b. ***Coding is relevant for building problem solving skills.*** A few students found value in developing critical thinking and problem solving skills. *"I do know I won't be writing any code, but a big component of coding is finding the problem and fixing it. This is necessary in any career."* Another student remarked that this skill was of more value to their future career than actually learning physics - *"...what's probably more helpful than the physics content is the ways that physics and coding teach me to think about our program... maybe [coding will] be helpful, but definitely thinking skills from the class will be helpful."* We briefly note parallel responses in our data about learning physics: whether or not the content or techniques apply, it is useful for problem solving and critical thinking.

c. ***Coding is useful as tool to calculate.*** Some students highlighted the ability to perform complex calculations with a computational model. One of our interviewees, a human biology major, had coding experience through a required statistics course, which officially used Rstudio, but in practice she could get away with using a TI-84 calculator. Prior to the course, she saw coding as an activity most useful for "computer-based" activities like making websites, but was starting to see value in performing complex calculations - *"Like, recently we had an [drag and viscosity] equation, and it's really difficult to do unless you know advanced calculus, but like we just put it in our code and then it gives us all the values out, which is super, super nice."*

d. ***Computational modeling as a tool to understand physics.*** Being able to translate between equations and computer code, tweaking the physics model, and in the process gaining better conceptual clarity is a very important reason to use computational modeling in the curriculum. Some students found the code useful in helping understand their physics model, specifically the effect of changing different variables - *"This code was useful with experimenting how different factors like mass and velocity impact collisions."* Another student remarked *"This code was a deeper dive into modeling slightly more complex scenarios... By using a program to model this, I was able to see the calculations behind the actual motion, and see how altering those calculations affects the actual simulation and motion of the objects."*

VI. DISCUSSION & OUTLOOK

In this exploratory study, we investigated the different ways in which students derive relevance towards computational modeling in an IPLS course. We find that students, broadly speaking, came to the course perceiving relevance in terms of data and visualization, and also pointed to current societal impacts of technology. Within our ES framework, this can be understood, since students from life science disciplines are likely to interact with computation strongly through a data-analytic perspective. We further see evidence of the Macrosystem increasing students' sense of relevance, with "computers are everywhere" being a common sentiment in student responses. On the other hand, students did not always see the relevance to learning physics. Most students who saw the code primarily as a visualization tool did not find the activities as valuable compared to other ways of learning, such as physical experiments. Instead, some felt the code improved their problem solving skills, and others had motivations to learn how to code for research or other courses. In contrast, some students did find computational modeling useful as a tool to perform complex calculations and also as a tool to learn physics by exploring relationships between the variables in their physics models. In this course, students and instructors referenced computational modeling as "coding activities," and for future studies it would be interesting to see if using the phrase "computational modeling" would further encourage students to find relevance to learn physics.

Future studies could more explicitly probe the correlations between sources of utility (e.g., visualization, calculation, or variable relationships) and students' perceptions of usefulness. Although the visual aspect of the coding activities may have helped novice coders get their footing, it may have unfortunately acted as a red herring, distracting students from the more significant uses of computation in physics, such as performing otherwise-intractable mathematical calculation and helping understand physics models. Future design of computational activities can benefit by more intentionally encouraging students to use computation as a tool for learning physics.

Our study involves primarily life science majors, who tend to be a large cohort in undergraduate physics classes. Engineering majors form another large population, and might be expected to have more coding experience or find more relevance towards computational modeling. Performing an analogous study to investigate relevance in this group would provide a more complete picture for a typical introductory physics course.

The heavy emphasis many students placed on data analysis and plotting in initial surveys suggests pedagogical strategies for enhancing relevance. Instructors looking to draw students in to computational activities might lean on this background in the beginning and introduce other aspects of CT over time. The use of Jupyter Notebooks, rather than VPython with GlowScript, might be better suited for this purpose. However, instructors should not assume students have programming experience, and need to find ways to incorporate computational lessons without increasing students' cognitive load.

ACKNOWLEDGMENTS

We thank Vashti Sawtelle for the helpful discussion on the theoretical aspects of our research design, and Bryan Stanley for helping us prepare effective interviews. We thank the participants and mentors in the SUTL fellowship at Lyman Briggs College, with a special thanks to program director Rachel Barnard. This work was performed while Watkins was a NSF Graduate Fellow, and while Watkins and Ivanov were SUTL fellows.

[1] N. R. Council *et al.*, Adapting to a changing world challenges and opportunities in undergraduate physics education, (2013).

[2] M. M. Cooper, M. D. Caballero, D. Ebert-May, C. L. Fata-Hartley, S. E. Jardeleza, J. S. Krajcik, J. T. Laverty, R. L. Matz, L. A. Posey, and S. M. Underwood, Challenge faculty to transform stem learning, Science **350**, 281 (2015).

[3] N. R. Council *et al.*, *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering* (National Academies Press, 2012).

[4] R. Chabay and B. Sherwood, Computational physics in the introductory calculus-based course, American Journal of Physics **76**, 307 (2008).

[5] J. M. Aiken, M. D. Caballero, S. S. Douglas, J. B. Burk, E. M. Scanlon, B. D. Thoms, and M. F. Schatz, Understanding student computational thinking with computational modeling, in *AIP Conference Proceedings*, Vol. 1513 (American Institute of Physics, 2013) pp. 46–49.

[6] C. Orban and R. Teeling-Smith, Computational thinking in introductory physics, The Physics Teacher **58**, 247 (2020).

[7] D. P. Weller, T. E. Bott, M. D. Caballero, and P. W. Irving, Development and illustration of a framework for computational thinking practices in introductory physics, arXiv:2105.07981 Phys. Rev. Phys. Educ. Res. **18**, 020106 (2022).

[8] A. Nair and V. Sawtelle, Operationalizing relevance in physics education: Using a systems view to expand our conception of making physics relevant, Physical Review Physics Education Research **15**, 020121 (2019).

[9] C. Walkington and M. Sherman, Using adaptive learning technologies to personalize instruction: The impact of interest-based scenarios on performance in algebra, The Future of Learning: Proceedings of the 10th International Conference of the Learning Sciences **1** (2012).

[10] K. K. McBride, Customizing Physics Courses for Non-Physics Majors Using Relevant Problems to Motivate Students, The Physics Teacher **61**, 71 (2023).

[11] B. R. Lunk and R. J. Beichner, Attitudes of life science majors towards computational modeling in introductory physics, in *Physics Education Research Conference* (2016) pp. 208–211.

[12] U. Bronfenbrenner and S. J. Ceci, Nature-nuture reconceptualized in developmental perspective: A bioecological model., Psychological review **101**, 568 (1994).

[13] K. Cummings, J. Marx, R. Thornton, and D. Kuhl, Evaluating innovation in studio physics, American journal of physics **67**, S38 (1999).

[14] E. Brewe and V. Sawtelle, Modelling instruction for university physics: examining the theory in practice, European Journal of Physics **39**, 054001 (2018).

[15] D. Scherer, P. Dubois, and B. Sherwood, Vpython: 3d interactive scientific graphics for students, Computing in Science & Engineering **2**, 56 (2000).

[16] B. Sherwood, Vpython, Online][Retrieved 19 February 2023] www. vpython. org (2017).

[17] B. Sherwood, Glowscript, Online][Retrieved 19 February 2023] www. glowscript. org (2017).

[18] S. Weatherford and R. Chabay, Student predictions of functional but incomplete example programs in introductory calculus-based physics, in *AIP Conference Proceedings*, Vol. 1513 (American Institute of Physics, 2013) pp. 42–45.

[19] C. Curtain, QualCoder (2023).