Mapping intent and impact of activity design in a computationally integrated physics course

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In this paper, we demonstrate the suitability of conjecture mapping for specifying misalignments between intent and impact of activity design. We situate our methodological inquiry in the context of a multi-day activity within a computationally integrated physics course, informed by data from interviews and ethnographic observations. Specifically, we consider affect through the theoretical frameworks of physics computational literacy and physics identity. We find that centering separate analyses on student and professor perspectives produces distinct conjecture maps that highlight misalignments in two different uses of mediating processes, which provides insight into the paths towards unintended affective outcomes.

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I. INTRODUCTION

Educators frequently design their courses to meet certain educational goals, but sometimes, these activities do not impact students as intended, cognitively or affectively. To minimize this mismatch, we need to learn how curricular design shapes the student experience by separating the intent behind instructors' decisions from the impact on students and characterizing what leads to potential misalignment.

In this paper, we demonstrate the suitability of conjecture mapping as an analytic method to distinguish between intent and impact. We aim to address the research question: "How can conjecture maps be used to understand differences between intent and impact?"

This paper is the first step in a larger project studying affective impacts of integrating computation into physics courses, where the literature is sparse [1, 2]. Teaching computation in physics may provide authentic experiences with the professional practices of physicists, but it may also serve as an additional barrier to success in physics. Perturbing the physics curriculum to integrate computation may change student notions of what it means to be a physicist and the extent to which they identify as such. We therefore use a case study of a multi-day activity in the context of a computationally integrated physics course to trace paths towards these affective outcomes.

A. Conjecture Mapping

Because the goal of this paper is to distinguish between the intent and impact of activity design, analysis calls for a method that can track continuities and discontinuities from design decisions to outcomes. To do this, we use the method of conjecture mapping, which explicates salient features of a learning community and outlines how they function together to generate outcomes [3]. Conjecture mapping begins with a conjecture: a high-level hypothesis about how outcomes are supported in a specific context. This conjecture manifests in embodiments that describe the learning environment, which in turn connect to mediating processes lead to the desired outcomes. In connecting data from interviews and observations, we use this method narratively to elicit the participants' underlying affect across data sources.

B. Theoretical Frameworks

In this case study, we consider affect through two theoretical frameworks: physics computational literacy (PCL) and physics identity (PI).

Computational literacy is the notion that computation enables new forms of learning and understanding, in ways analogous to the literacies of reading, writing, and math [4]. Odden, Lockwood, and Caballero defined computational literacy in the context of physics, coining PCL [5]. They claimed that PCL consists of three components:

- **Material:** familiarity and fluency with the mechanics of coding, including syntax;
- **Cognitive:** applying computing to solve physics problems and extend one's understanding of physics;
- **Social:** collaborating and/or communicating with or about computing.

Odden and Zwickl further developed this theory in what we have found to be the only use of conjecture mapping in PER, primarily centering students' concrete interactions with the construction of code [6]. In doing so, they focused on PCL practices and knowledge, leaving the development of PCL beliefs – attitudes and value judgements about computation [5] – understudied. This trend extends across much of the existing PCL literature [5–7]. In part, we characterize affective outcomes in this paper by considering a student's PCL beliefs in two ways: feelings towards the development of her own PCL and her perceptions of how PCL is supported within her computationally integrated physics course.

In this paper, we also trace affective outcomes by examining how a specific activity design impacts a student's PI. Hazari, et al. defined PI as a student's self-perception as a physicist, composed of the following constructs [8, 9]:

- **Performance/Competence:** belief in one's ability to understand physics content and/or perform physics tasks;
- **Recognition:** belief that one is perceived by others as a physics person;
- **Interest:** personal desire or curiosity to learn and/or understand more physics;
- **Sense of Belonging:** one's perception of fitting in or not feeling excluded in the/their physics community.

While PI has been studied in a variety of physics contexts [10–16], it has rarely been studied in computationally integrated physics courses. However, Lane and Headley addressed some of these constructs in such a context by studying students' alignment with a community of practice [2].

II. METHODS

We use a computationally integrated upper-level modern physics laboratory course as the context of this case study. This course consists of two weekly meetings: a 50-minute lecture and a 3-hour lab. The lecture component of this course rarely demonstrated the use of code but concentrated on statistical methods central to the physics analyses used in the laboratory component, e.g., highlighting linear fits characterized by χ_r^2. The professor designed a multi-day activity for the end of the semester which consisted of an in-class exercise situated between two homework assignments.

In the first associated homework assignment, students developed code to calculate a goodness of fit parameter, reduced chi-squared (χ_r^2), for a fit to a power law distribution by looping over one fit parameter while holding the other fit parameter constant. Students also plotted the resulting χ_r^2 surface.

This was the first time students calculated χ_r^2 without linearizing the distribution and the first time `for` loops were used in the course. In lecture the week before this assignment, the professor directed students towards references to learn about `for` loops, both from class materials and the internet.

The in-class exercise asked students to annotate provided code that used nested `for` loops to conduct a 2-dimensional grid search to find the fit parameters by minimizing χ_r^2. In class, students were also asked to determine what changes the program needed to fit to a different function.

The homework assigned after this in-class exercise asked students to implement the components addressed during the in-class exercise and produce a 3-dimensional plot of the χ_r^2 surface with the grid search's path overlaid.

This paper focuses on one student's experience with this multi-day activity and contextualizes her experience with her professor's perspective. To understand the professor's intent behind her design decisions and the impacts on a student, the first author conducted semi-structured interviews and ethnographic course observations.

To create the conjecture maps, the first author used the professor's interviews and observational data as the primary data for intent and the student's interviews and observational data as the primary data for impact. The first author deductively coded interview transcripts through the constructs of PCL and PI and discussed codes with other researchers until convergence. Then, the first author used a combination of interview and observational data to identify embodiments and mediating processes, with the former reflecting perceptions of the activity design and the latter reflecting engagement with the activity. While constructing the conjecture maps, the first author logged data sources and analytic decisions and discussed with the second and third authors until reaching consensus. Because we specifically track the development of affective outcomes with this method, connections on the maps characterize the respective linkage as having either positive or negative affect. The conjecture maps shown in this paper (Fig. 1 and Fig. 2) only include categories and connections mentioned in this case study.

III. RESULTS

A. Intent: Professor's Perspective

Our characterization of the professor's intentions for the activity, as related to student PCL and PI, is given in Figure 1. In an interview, the professor expressed that she did not view the course as a class on coding and hoped that the "structure will tide [students] through where they learn [the coding language] at the beginning, they have resources that they can go back to, and that they learn by doing over and over and over again." With this framing, we consider her to have prioritized cognitive PCL and decentered material PCL by outsourcing syntax as something that students learned through supplementary resources. Because the professor structured the assignment to provide solutions before and during the in-class exercise, we categorize reviewing solutions as an intended mediating process towards material PCL.

The professor positioned computation as part of the professional practices of physicists and wanted it "to be in the service of understanding how to do lab." In the context of this activity, she announced in class that it was a more realistic extension of the analysis techniques students had used thus far. Her framing of the activity connected it to what physicists actually do, which she hoped would help students feel like they were part of the community of physicists by gaining competence the a relevant skill of connecting coding to physics. The professor further clarified her motivation in an interview, where she stated that she believed this course played an important role in students' self-identification as physicists: "I think [this course] is a crucial point in their development. And I hope and feel that it was successful in making them feel like we're kind of all in this together... [I'm] trying to bring in topics that are what I'm involved in now so that they can feel that what they're doing in the lab really is like doing an experiment and that this is what it feels like." With this in mind, we consider the development of students' physics identities to be one of the professor's goals, specifically by developing performance/competence.

In what we consider to be a prioritization of social PCL, the professor asked students to work together to complete the in-class exercise. During an interview after the multi-day activity, she positively assessed the efficacy of the in-class exercise because of how much students interacted with each other, which she also used to gauge students' sense of belonging: "Watching student interactions there, I had the feeling that they kind of got into it and meaning that by that time, I didn't see anyone who was sitting back and not participating... You could really get a sense that most of them were participating or answering questions...You can see a sense of *not* belonging very clearly when you have groups of people talking and one person doesn't talk, they don't want to ask the questions, they don't want their ignorance to be showing. But if people ask questions and let their ignorance be shown, they already feel confident that they're part of the group and that those questions might be shared by other people."

B. Impact: Student's Perspective

Our characterization of the activity's impact on the student, as related to PCL and PI, is given in Figure 2. In an interview, the student reported approaching the associated homework individually because she felt she understood the underlying concepts from lecture. This led her to hope that she could learn the syntax she didn't know how to implement by reviewing the posted solutions: "It didn't make me feel confident in that week's homework assignment or lecture because when I'm listening to lecture, I understand the concepts being told but executing it was just something I wasn't able to do. So it was more like I'll turn in what I have and once the homework answers are posted, I can go through that and see how they're able to do it."

However, the solutions to the first associated homework assignment were not posted until the day of the in-class exercise, so the student inherited frustration with material PCL. This feeling continued when she could not understand the solutions provided during the in-class exercise deeply enough to complete the subsequent assignment: "I just copy-pasted it and ran it through after. But it was a bit confusing as to what I was supposed to do to make the code work."

In a step towards social PCL, the student met up with a classmate outside of class to discuss her code, but she only discussed the ideas behind her code rather than the syntax. The student believed that she should only discuss logic, as opposed to syntax, because of her experience in a computer science (CS) course where she first learned how to code: "[In that class,] they were very strict on [not] sharing code, which I understand... So they would crack down on if you shared code with other people." Her collaborative approach centered cognitive PCL but prevented her from resolving her difficulties with material PCL: "I reviewed my thinking process and code with someone else and we had the same thought process for, like, I had implemented it concept wise, but I wasn't able to debug it fully. And then because of that, the next homework assignment didn't really click as easily as well... I think it was not great for that self-confidence in physics because there are people who knew [the coding language] really well and they were able to do the assignment." This consultation led to a form of solidarity that she described as, "if we go down, we'll go down together." This reframing helped the student move from viewing her own difficulties as a personal weakness to a shared struggle and increased her sense of belonging. Even though the professor designed the in-class exercise to use group work, this out-of-class consultation was the only instance of group work that the student reported for this multi-day activity, and the first author observed that the student worked alone for the entire in-class exercise.

While the student understood the professor's intended framing of the activity, she did so with negative affect, both in the way it connected to the structural components of the activity and to her cognitive and social PCL. To the student, the framing of this activity deviated from the framing of computation used throughout the course: "You can use it for nonlinear fitting, but we were never asked to do that in our labs. And you could always linearize everything... So whereas it's useful information in the future, it just didn't apply to this class. I think it added a bit more stress than it needed to."

C. Conjecture Maps

Viewed together, the two conjecture maps show differences between the professor's intentions for the activity (Fig. 1) and the resulting impact on the student's PCL and PI (Fig. 2) as introduced in Sections III.A and III.B, respectively. We classified misalignments between the figures in two ways: unforeseen mediating processes and intended mediating processes used differently than expected.

Unforeseen Mediating Processes: In the context of this activity, the student did not participate in group work during the in-class exercise as the professor intended, so these connections from Fig. 1 do not appear in Fig. 2. The student's confidence from lecture motivated her to code alone for the homework, but after struggling with the homework, she discussed the ideas behind her code with a classmate outside of class. We connect these structural embodiments, lecture and homework, to the respective mediating processes, solitary coding and discussing ideas behind code, with positive affect because the student felt positively towards her decision. However, her approach did not address the syntax she struggled to understand on her own, as shown in the negative connections from the unforeseen mediating processes of solitary coding and discussing ideas behind code to material PCL. Discussing ideas also connected to her social PCL with positive affect because she embraced collaboration to face a difficulty by discussing ideas behind her code. This did not help her feel better about her own ability to solve the problem but did make her feel like she wasn't the only one struggling, so we connect that mediating process to performance/competence with negative affect and to sense of belonging with positive affect. Even though the student was not able to debug her code, she felt confident in understanding what her code should do, so both solitary coding and discussing ideas connected positively to cognitive PCL.

Mediating Processes Used Differently: Reviewing solutions differed as a mediating process between Fig. 1 and Fig. 2 partly because the timeline on which solutions were posted did not offer the positive material PCL support that the professor intended. When the student did engage with the provided solutions during and after the in-class exercise, she did so with negative affect because of the mismatch in material PCL, reflected in her struggle to understand syntax. The professor thought specific tools and materials would help students develop material PCL by reviewing solutions, with positive affect throughout. However, the student engaged with structural rather than resource-based embodiments, which connected with mixed affect to reviewing solutions. That mediating process then connected to material PCL and performance/competence with negative affect. The professor's decentering of material PCL and the student's pre-existing computational literacy beliefs did not provide the student with the resilience to transcend the challenges she faced with material PCL when reading the solutions.

Connecting coding to the practices of physicists also differed as a mediating process between Fig. 1 and Fig. 2. The professor believed that this multi-day activity would connect coding to the professional practices of physicists, which would in turn help students both develop cognitive PCL and see themselves as physicists through performance/competence and sense of belonging. This did not manifest for the student because this activity situated the professional practice differently than in the rest of the course. As

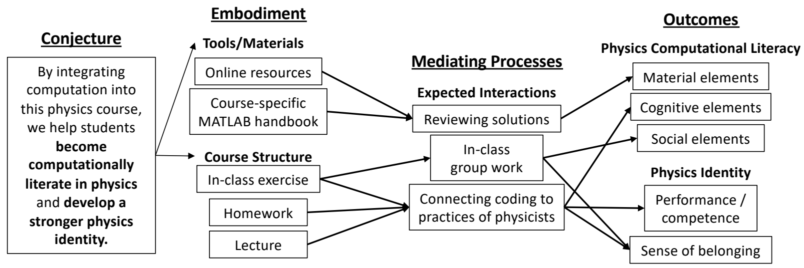

FIG. 1. Conjecture map of the professor's perspective of a multi-day activity. Connections with positive affect are shown as solid arrows.

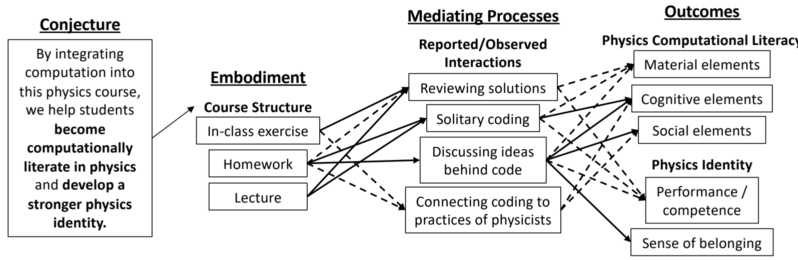

FIG. 2. Conjecture map of the student's perspective of a multi-day activity. Connections with positive affect are shown as solid arrows, and connections with negative affect are shown as dashed arrows.

such, the student experienced negative affect from the structural embodiment through the intended mediating practice to cognitive and social PCL.

IV. DISCUSSION & LIMITATIONS

The conjecture maps presented in this paper illustrate the role of activity design in the development of unintended affective outcomes through two manifestations of mediating processes.

In this example, the student's use of unforeseen mediating processes resulted in a mix of positive and negative affect towards both PCL and PI. We attribute the source of this misalignment to the student's preexisting computational literacy beliefs. She applied the social PCL beliefs she developed in a CS course, where she learned the practice of discussing logic rather than syntax. In the context of this multi-day activity, collaborative norms were not discussed, and negative affect arose from her choice of mediating process because she did not address the component of PCL with which she struggled.

When the student used an intended mediating process differently than anticipated, connections to outcomes had negative affect. We attribute this to structural contrasts between the course and the activity that limited the extent to which the student could use the mediating processes as the professor intended.

While an instructor cannot control an individual student's pre-course PCL beliefs, being aware of them could allow the instructor to communicate desired norms. In this case study, conjecture mapping showed a student's need for clarified collaborative expectations in coding and a clearer delineation between getting help debugging syntax and plagiarism. By highlighting a student's frustration when extending beyond typical course assignments, this method also helped to clarify what caused sources of structural mismatch that led to negative affect.

Conjecture mapping has limitations as an analytic method. In particular, we investigated a predetermined hypothesis and did not consider alternative outcomes for student affect. This arose from our decision to align deductively-coded outcomes with the conjecture. We encourage exploration of this method in PER with inductively coded outcomes.

We also acknowledge that our demonstration of this methodology is limited by the scope of our case study. In future work, we plan to expand this method to include additional perspectives on this same activity.

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