How do previous coding experiences influence undergraduate physics students?

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Electricity and Magnetism Projects and Practices in Physics (EMP-Cubed), a section of introductory, calculus based physics, is designed around problem based learning. Students spend each class working in groups on a single complex physics problem. Some of these problems are computational in nature—students start with code from a visual computer program that runs without accurately accounting for the physics, and they spend the class period applying the physics concepts correctly in the program. Here we present an interview study that investigates the relationship between students' prior computational experiences and their experience with computational activities in EMP-Cubed. This investigation demonstrates the ways by which prior coding experience can impact how students make sense of computation within physics.

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I. INTRODUCTION AND CONTEXT

The prevalence of computational integration into STEM classrooms [1] is owed in part to calls from the Next Generation Science Standards [2] for introducing the practice of "computational thinking." This change in the landscape of STEM curricula across the United States brings about the need for research into how the integration of computation in classrooms impacts students. Several studies have begun to explore this space. Taub *et al.* [3] found that computation can help students build their abstract problem-solving techniques. Chabay and Sherwood [4] developed a computational physics curriculum and described similar benefits.

The context for our study is a physics course into which computational activities have been incorporated. Electricity and Magnetism Projects and Practices in Physics (EMP-Cubed) is an introductory, calculus-based, undergraduate course with a flipped design, modelled after P-Cubed, a mechanics course [5] at Michigan State University (MSU). In EMP-Cubed, students solve complex physics problems in groups, some of which use computer programming to visually model physics concepts by adding to and manipulating existing minimally working programs. The majority of students in the class are engineering majors, many of whom already have experiences with computational practices. This raises questions around how students with coding backgrounds take up the computational physics practices in EMP-Cubed, and how they make meaning of these computation-within-physics experiences.

Existing research related to the student experience of this computation/physics intersection has mainly addressed each field separately. Hazari *et al.* [6] developed a framework for physics identity to investigate persistence and help teachers operationalize physics identity. Close *et al.* [7] adapted this framework to be used in a practice-based way. This helps us in understanding how we can adapt Hazari *et al.*'s framework for coding and computational physics. In computation, Peters and Pears [8] connected identity development for computer science students to in-class engagement. Fields and Enyedy [9] took a practice-based view of computer science identity to investigate peer-recognition of expertise. The findings of these identity studies in physics and computation pave the way for papers like this one, in which we apply an adapted identity framework to show how three undergraduate students formed new academic identities in order to make sense of computational activities in a physics context.

II. CONCEPTUAL FRAMEWORK

We mainly adhere to a framework established by Hazari *et al.* [6], which we adapt slightly for a practice-based view on identity, similar to how Close *et al.* [7] adapted the same framework for their own study on LAs. Close *et al.*'s framework tied together a communities of practice[10, 11] perspective on identity and Hazari *et al.*'s physics identity framework, originally constructed by Carlone and Johnson [12] for science. Four primary factors influence our view of practice-based identity: competence, performance, recognition, and interest. We have adapted the definitions of these factors for the context of our study: *Competence* and *performance* refer to belief in ability to understand material and perform required tasks, respectively. *Recognition* refers to the perceptions of students' coding abilities, held both by the students themselves and their peers. *Interest* refers to a student's desire to learn or engage in a given practice.

This construction of identity allows for a differentiation between contexts. Nasir [13], a pioneer of academic identity as we intend to use it, viewed identity as a fluid construct which changes relative to the social setting in which the identity is being developed; students take up different identities in different contexts. We consider computation in two separate environments: individual students' previous coding experiences and EMP-Cubed—both can be productively analyzed as communities of practice [10]. We differentiate between past coding and EMP-Cubed because students drew several distinctions when discussing practices in each context. Though the previous coding experiences took place in multiple environments, we discuss them under the umbrella of "coding"—each of our interviewees described engaging in similar practices associated with coding in their past experiences.

The students' individual conceptions of coding were created during their previous experiences, and the computational activities in EMP-Cubed did not match these conceptions. In short, this choice to view computation in two classroom contexts was a data-driven decision. Our framework permits us to analyze the development of a *new* practice-dependent academic identity as students make sense of the computational activities. In particular, we apply Hazari *et al.*'s framework [6] to students with dual computational experiences—one in a previous course, and one in EMP-Cubed.

III. METHODS AND DATA GENERATION

We did an interview study because our focus lies in the student perspective on computation-within-physics. By conducting semi-structured student interviews [14], we intended to elicit beliefs that would allow us to understand the academic identities of our participants. We interviewed three students: Mark, Isaiah, and Sarah (pseudonyms). Each student participated in a 45-minute semi-structured interview in the last month of the semester during which they were enrolled in EMP-Cubed. Mark, Isaiah, and Sarah all had different computational backgrounds and levels of interest in computer science as a whole. They were selected because they had prior coding experiences, which was the focus of this study.

At the time of the interviews, Mark, a Southeast Asian male, was a sophomore actuarial science major who completed various computer science courses at MSU and also had experience coding in high school. He had worked with various languages including Python, C++, Axel, and LaTeX. Isaiah, a White male, was a junior who had recently switched his major to computer science after taking an introductory computer science course using Excel. Isaiah focused on one course as he talked about his previous coding experience and described its learning goal as gaining "practice with various data structures." Sarah, a White female, was a senior pursuing a statistics degree with a computer science minor. During the interview, she discussed a previous coding experience which she found very challenging but also very rewarding. Sarah articulated a very high level of interest in coding.

Our interview protocol focused on comparing previous coding experiences with EMP-Cubed. We wrote questions to elicit the four identity factors from our conceptual framework. We updated the protocol iteratively by rewriting follow-up questions to create a more comprehensive view of the relationship between past coding experiences and EMP-Cubed. We operationalize certain terms in our analysis based on how they were defined by the participants. One such word is *success*, a topic of discussion during the interviews that led us to understand the roles of several factors, primarily *competence* and *performance*, in the formation of identity. We use the word *success* as our participants did, for we wish to preserve the student perspective where reasonable. We also use certain synonyms for "computation," such as "coding" and "computer programming," which students used to refer to activities involving any substantial writing of computer code. We roughly adopt the students' language convention because in some claims, using the wrong word (e.g., "computation identity" instead of "coding identity") would not accurately reflect the student perspective.

IV. ANALYSIS AND DISCUSSION

The participants developed individual coding identities and conceptions of coding according to their previous experiences. When confronted with the computational activities in EMP-Cubed, they experienced a disconnect between computation-within-physics practices and their existing conceptions of coding. In order to make sense of the EMP-Cubed experience, we argue that the students formed new academic identities specific to the EMP-Cubed computational activities. This process of identity formation is what we detail in the following analysis.

A. Students have previously-developed coding identities

By reviewing statements made by Mark, Isaiah, and Sarah about their previous coding experiences, we analyze the formation of their coding identities through competence, performance, recognition, and interest. The students also identified personal indicators of "coding success" within relevant classroom communities. We focus our analysis on student-defined indicators of *success*, for the students' indicators of success in both learning environments were constructed of the four identity factors.

All three students discussed success in coding activities from their previous experiences in similar ways. From the following statements, we can see that the students felt competent at coding to various degrees through learning new concepts and developing understanding. Mark's reasons for feeling successful during his previous coding experience are recorded below.

> Mark: *"Why do I say [I was successful]? I learned a lot of stuff for coding. I got a good grade in the class too. I feel like I'm better at coding in general after taking that class."*

Mark measured his performance through the grades he earned and he had a perceived level of competence based on the amount of coding concepts he learned. He took a holistic look at the course and recognized his improvement in coding, which led to his feelings of success. Mark mentioned feeling most unsuccessful when projects took a long time for him to complete. Similarly, Isaiah also often felt successful in his relatively difficult computer science course.

> Isaiah: *"For the most part I feel like I'm successful. I'm learning a lot. I really get a good understanding of what's happening behind the scenes."*

In responses to follow-up questions, Isaiah expressed that his perceived high level of comprehension, which we identify as competence, was essential for experiencing coding success. In the following reflection about success from Sarah, we notice that she focused on how the projects made her feel.

> Sarah: *"Every time I finally finished my project I felt so good about myself...I felt smart and capable and was like, 'This is awesome I finished my project and it was super hard'...The combination of liking what you're doing and feeling that it's useful makes you feel like you're more successful...and I did really well on the exams."*

Sarah's response highlights the importance of interest and purpose as metrics of coding success. She used her exam scores and project completion to measure her performance, and used her feelings of intelligence to gauge her competence. While not all three students considered themselves good at coding, it is clear that they experienced feelings of coding success on previous projects. The students felt more competent as they developed understanding, which played a significant role in the development of their coding identities.

B. Rejection of EMP-Cubed computation as "coding"

We also observe that the students subconsciously created definitions of coding itself, specific to the practices within their previous coding experiences. The coding projects the students completed in these courses often required them to spend lots of time outside of class, independently creating code from scratch. As the students were presented with EMP-Cubed computational activities, these predetermined specifications of coding activities were not met. This led the students to reject the classification of the EMP-Cubed computational activities as authentic "coding."

The three students outlined their personal definitions of "coding." We demonstrated earlier that these students saw coding success in terms of learning concepts and developing understanding. Mark made a comment that EMP-Cubed did not align with this definition:

> Mark: *"I don't really feel EMP-Cubed is coding itself because I don't really learn anything...for CSE 201, I learned coding."*

Isaiah and Sarah explained further what coding practices looked like to them—coding was mainly a creative process with minimal scaffolding. Like Mark, they saw EMP-Cubed separately from coding.

> Isaiah: *"It's not technically programming because it's not like you're starting from scratch.*
>
> Sarah: *[In EMP-Cubed,] you're not creating anything! The code is set up for you..."*

We see that the computational projects in EMP-Cubed did not match their previous definitions of coding, which supports our argument that these students did not use their previously developed coding identities in the new context. Though the projects involved computer code, the students viewed them as inauthentic. In order approach the new context, they developed new academic identities.

C. Development of new academic identity within EMP-Cubed

1. Redefinition of success: Here we analyze the formation of the new EMP-Cubed identities. Students did not appear to extend their previous definitions of success to EMP-Cubed computational activities, for they already claimed that EMP-Cubed computational activities were not technically coding. As the experienced students created their EMP-Cubed identities within the new classroom context, they also determined new indicators of success which differed from those set previously. Through analyzing the students' indicators of success in EMP-Cubed and in their previous experiences, we notice that they are constructed of the identity factors from our framework.

The students previously mentioned learning new coding concepts being a crucial component of experiencing success. However, all three students felt successful at the EMP-Cubed computational activities even though they did not feel like they were learning coding concepts. Some of their indicators of success in EMP-Cubed, including level of comprehension and completion of a task in a relatively short amount of time, can be seen in the following student responses.

> Mark: *"Usually I feel successful when I understand everything before the end of the class because usually the [coding] project took a lot of time... I find myself understanding if I can finish the project."*

In this response, we see how leaving class with an understanding of how his group solved the computational problem gives Mark a high level of competence. After additional reflection following this quote in the interview, he arrived at the decision that finishing the project made him feel most successful. Mark did not place the same emphasis on learning coding concepts in EMP-Cubed as he did when discussing success in his previous coding experience. In the following response Isaiah emphasized how understanding the material and finishing the projects relatively quickly with minimal setbacks led him to feel successful.

> Isaiah: *"Cranked through it...the material was pretty easy to understand and there wasn't a whole lot to change...I don't remember getting stuck to a point where we didn't finish...for the coding, we get out of there quick[ly] and I feel like I get a better understanding."*

We observe that Isaiah perceived himself to have high levels of competence and performance for the EMP-Cubed computational activities as he focused on his completion of projects and level of comprehension. In Isaiah's previous coding experience, he defined success in terms of learning new concepts and understanding code, whereas for EMP-Cubed success means finishing quickly and understanding physics ("the material"). In the next comment, we also see that Sarah focused on this theme of understanding when talking about EMP-Cubed success.

> Sarah: *"I think if you understand the concepts fairly well within the duration of the class period...I feel like you're successful...This is from a stats major who doesn't use physics and I'm just filling requirements."*

Here, Sarah's lack of interest and purpose for the physics computational activities tells us about her perception of her place within the EMP-Cubed community. Sarah's indicators of success differed greatly in EMP-Cubed compared to her previous coding community. Her lack of interest in computational physics practices indicates a significant shift in one of the factors of identity from our conceptual framework.

We claim that students' definitions of success between the two contexts differed based on practices. The three students defined coding success as learning new concepts and completing difficult, time consuming projects. This differed from their definitions of success for the EMP-Cubed community of practice—completing projects in a short amount of time, with relative ease and a good understanding.

2. Peer and self recognition of coding expertise: The students' coding abilities being recognized by themselves and their peers is essential to the development of their academic identities. While there was no indication of recognition of coding expertise within their previous coding experiences based on interview responses, in EMP-Cubed, these students were recognized by their peers as skilled practitioners of coding because they had a deep understanding of the basic coding concepts and relevant data structures.

Even if the expert students did not have high confidence in their coding abilities in the past, the experience and knowledge gained from their previous coding experience allowed them to feel like competent, recognized, good coders within the EMP-Cubed context. The expert students expressed feelings of confidence as they approached EMP-Cubed computational activities, as seen in Sarah's comment below.

> Sarah: *"[The success I felt in CSE 231] probably gave me a lot of confidence going into them. Like this is nothing compared to the projects I had to do so if it's a thing you can do in an hour and a half, then you're good."*

Sarah compared the practices of the two communities, along with her competence and performance in each one. This comparison led Sarah to classify the EMP-Cubed projects as "do[able] in an hour and a half," in other words "nothing compared to the [non-EMP-Cubed] projects." Mark took a similar stance and claimed that the primary reason he was interested in the EMP-Cubed activities at all was due to the fact that they were "easy." Isaiah discussed his confidence with the EMP-Cubed activities and framed it in terms of his self-recognition and the recognition he received from his group members.

> Isaiah: *"I do get excited when they're like 'It's a coding day' because this is my strength and I get to practice and work in my true major. And I also feel a little bit more confident, especially when people are like 'Oh my God I don't know how to code, I'm gonna lean on you."'*

We observe that Isaiah embraced his position as an expert, and through other statements from the interview we learn that he enjoyed teaching other people because it helped him solidify his own understanding. Similarly, we see below that Sarah took on a teaching role and recognized herself as an expert because of her pursuit of a computer science minor.

> Sarah: *"I think during coding days I was...one of the main people moving ideas along, just because I was going to go for a computer science minor, so I kind of know what I'm doing...it's like who knows how to code... do it and then explain it to everybody else."*

Sarah mentioned that she explained how to code to her group members, and similarly, Mark mentioned in his interview that he took on a teaching role even though he did not enjoy putting in the extra effort. In this final analysis, we observe that Mark, Isaiah, and Sarah were recognized as experts by themselves and their peers, which led them to further develop their EMP-Cubed identities.

V. CONCLUSIONS AND IMPLICATIONS

This study observed how students' previous coding experiences influenced their engagement with the practices in EMP-Cubed and their perceptions of their positions as expert coders within the EMP-Cubed community of practice. We observed the formation of distinct academic identities, specific to the EMP-Cubed context, which differed from their original coding identities. Before enrolling in EMP-Cubed, the students developed coding identities in their previous coding experiences through competence, performance, recognition, and interest. We identified this as they discussed indicators of success, and we understood it more fully by using a slightly adapted version of Hazari *et al.*'s framework [6]. The students also created individual definitions of coding, specific to the practices of their previous coding experiences. All three students explicitly rejected the classification of EMP-Cubed projects as "coding." To make sense of these projects, we claim that the students began to develop new academic identities within the context of EMP-Cubed.

Our claim of identity formation is supported by how the students reframed indicators of success for the practices in the new community. These indicators were composed of the competence, performance, and interest factors of identity in different ways than in their previous coding experiences. Through additional analysis, we showed how the EMP-Cubed computational identities developed further as the students were recognized as coding experts by themselves and their peers. We were able to understand this by drawing on similar, more detailed work by Fields and Enyedy [9]. We also would like to acknowledge the gendered and racialized nature of coding identity and draw attention to the limited representation among our predominantly White or male interviewees. The results of our study are also limited in the sense that identity development goes much deeper than the treatment given here; a more in-depth study on the intersections between coding identity, gender identity, and racial identity is warranted.

We outline three potential implications from the conclusions of our study. (1) These students felt very competent when confronted with the EMP-Cubed computational activities due to their past experience with coding and the recognition of their peers. This raises the question if students without computer science backgrounds may feel ill-equipped to engage with the computational activities. (2) It would be interesting to investigate what perceptions of coding and computation develop as non computer science students experience the EMP-Cubed projects and coding, even while more experienced peers might not view the projects as "real" coding. (3) The interviewed students saw EMP-Cubed activities not as coding, but primarily physics. If indeed the computational activities were viewed as physics practices despite their computational appearance, then this would confirm a desired outcome of the curriculum design (though may raise other concerns about how the code is helping students learn). Future work could address this implication by investigating the perspectives of students who do not have previous coding experiences. In presenting our own investigation of identity formation in an undergraduate computation-within-physics setting, we urge others to continue to uncover how students are experiencing computational integration.

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