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Computer Science beyond Coding: Partnering to Create Teacher Cybersecurity Microcredentials

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Abstract: Computer science, cybersecurity education, and microcredentials are becoming more pervasive in all levels of the educational system. The purpose of this study was partnering with precollegiate teachers: (1) to investigate the self-efficacy of 30 precollegiate teacher participants towards computer science before, during, and after three iterations of a cybersecurity microcredential, and (2) to make changes to the cybersecurity microcredential to improve its effectiveness. The authors explored what teachers need in a microcredential. The first Cohort (n = 5) took the microcredential sequence over 28 days in the summer of 2020, the second Cohort (n = 16) took it over 42 days in the fall of 2020, and the third Cohort (n = 9) took it over 49 days in the summer of 2021. The authors investigated three research questions and used a systems thinking approach while developing, evaluating, and implementing the research study. The researchers used quantitative methods in the collection of a self-efficacy subscale survey to assess whether the precollegiate teachers' beliefs about computer science changed, and then used qualitative methods when conducting semi-structured teacher participant interviews to address the research questions. The findings show that the precollegiate teachers' self-efficacy scores towards computer science increased, and that there are areas in need of attention, such as resources and implementation, when creating microcredentials. The implications of this research include the importance of purposefully crafting microcredentials and professional developments, including aspects of creating effective partnerships.

Keywords: microcredential; cybersecurity education; computer science; systems thinking; precollegiate teachers; self-efficacy; STEM; coding; partnership; professional development

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1. Challenge in Science Teacher Education

Throughout 2020 and 2021, primarily due to the ongoing COVID-19 pandemic, virtual learning became a reality for many people, including precollegiate students [1,2]. While the pandemic has adversely affected students, it has also impacted precollegiate teachers' access to professional development (PD) at local, national, and international levels [3]. To retain access to PDs, many precollegiate PD providers and teachers moved from holding in-person PDs to virtual PDs. Virtual PDs can offer new formats such as microcredentials [4]. The microcredential module set discussed throughout this work was developed with partners spanning a state department of education, a state university, industry partners, and teacher practitioners. Microcredentials provide teachers an opportunity to learn and complete materials asynchronously at their own pace. Instead of the continuous day-long or week-long instruction which occurs in many PDs, microcredentials are virtual, self-paced, and allow flexibility over longer periods of time [5–8]. With this in mind, one challenge is finding out how precollegiate teachers perceive a cybersecurity microcredential PD, how it impacts their self-efficacy, and how the most effective microcredential can be coconstructed. The concept of an effective microcredential is important because educational researchers recognize that learning the principles of computer science (CS), computational thinking, and cybersecurity promote thinking creatively [9–12], and this can benefit disciplinary integration within Science, Technology, Engineering, and Mathematics (STEM) [13,14].

While microcredentials may ultimately take the form of a digital badge, regardless of their representation, they serve as evidence of a skill or learning [15], and this research study involved microcredential modules, specifically about cybersecurity, as they are embedded within computer science content. Computer science is, at its core, problem solving, or specifically, how to manipulate computational devices to solve problems with data. Although many not acquainted with computer science might think that it focuses solely on coding [16], and there are research studies focused on teaching coding [17], there are computer science skills that can be taught at any age or grade level, both with and without a computer [18,19].

Though cybersecurity is traditionally thought of as a subfield of computer science, focused on the security of devices, the field focuses on all aspects of securing computing systems—from politics, psychology, ethics, and society implications to how information is stored, processed, and transmitted. Cybersecurity's focus ranges from how individuals interact with traditional computing devices to how to insure advanced and distributed systems support modern-day society [20]. The broader field of security has always been a highly interdisciplinary and integrated field, requiring domain experts from the social sciences as well as the STEM fields to model, predict, investigate, understand, and prevent attacks [21,22]. Depending on the specific cybersecurity problems, it can require knowledge that includes but is not limited to:

Science—an understanding of physical, chemical, and electrical systems and device physics;

Technology—computing systems, networks, communication infrastructure, and mobile devices;

Engineering—system designs, problem solving, and constraint/resilient infrastructure;

Mathematics—logic, modeling, and algorithms; encryption/encoding, information theory, set theory, and quantum computing.

In many practical instances, solving cybersecurity challenges requires a transdisciplinary approach, where disciplines cannot be easily teased apart and require the knowledge of multiple spaces simultaneously. In educational realms, this can be emulated in interdisciplinary challenges and projects [10,23]. Educational literature shows that, in general, if you teach 'something', that the participants will generally learn 'something' and also like it more along the way [24,25]. An online PD study showed that areas in need of attention include matching PDs to the teachers' backgrounds, aligning the PD with curricula, and using motivational design to enhance teacher engagement [26]. The authors of this article investigated alignment with these concepts within computer science and cybersecurity, partnered with precollegiate teachers, and probed teacher needs in the microcredential.

2. The Framework

In approaching the problem of a microcredential's impact while creating a more effective microcredential model, the authors used a systems thinking framework. The systems thinking framework considers the end-user's experience, in this case, precollegiate CS and STEM teachers, as well as the problem to be solved [27,28]. This approach is started by identifying the common problems/barriers to implementation, and in this study the authors used it to identify the needs of precollegiate teachers. The systems thinking framework assists in identifying the problem, in this case, the interaction of precollegiate teachers with other human factors and their interactions with the microcredential platform and resources. The end stage of systems thinking covers the needs of the user beyond merely solving the problem [29]. Systems thinking does not break the process down into pieces, but instead keeps everything connected [30]. Therefore, the authors used the systems thinking framework to focus on possible factors such as a user-friendly platform, content-richness, and competency-based, cybersecurity-friendly pedagogies to meet the main problems of crafting an effective and efficient microcredential product [9,10,31].

The authors of this work prototyped and tested three microcredential iterations (called Pilot 1, 2, and 3), each with multiple modules, to investigate a cybersecurity microcredential's impact on precollegiate teachers and to explore what makes a high-quality microcredential. The authors posit that a high-quality microcredential would include user-friendly spaces, content-rich resources, and use a mastery-based approach in a microcredential for precollegiate CS and STEM teachers. Microcredential prototype processes were envisioned to be teacher-oriented. In particular, beliefs, behaviors, and emotions were important considerations of the microcredential development process. The precollegiate teachers were also included in the development process as partners, as their feedback, insights, emotions, and behaviors were all considered by the authors.

3. Study and Research Questions

Computer science, cybersecurity education, and microcredentials are becoming more pervasive in all levels of the educational system [4,10]. The purpose of this study was twofold: (1) to investigate the self-efficacy of 30 precollegiate teacher participants towards computer science before, during, and after three iterations of a cybersecurity microcredential and (2) to make changes to the microcredential to improve its effectiveness. To address these issues, the following research questions were explored:

Research Question 1 (RQ1). *How does a cybersecurity microcredential impact precollegiate teachers' computer science self-efficacy?*

Research Question 2 (RQ2). *How much time do precollegiate teachers spend in a microcredential?*

Research Question 3 (RQ3). *How do precollegiate teachers shape a microcredential to be more effective for teacher needs?*

4. Methods and Analysis

The authors used both quantitative measures (survey responses for precollegiate teacher self-efficacy) and qualitative measures (semistructured interviews for microcredential suggestions). The study involved 30 self-selected precollegiate teacher participants across three Cohorts, and these participants included 22 females (73%) and 8 males (27%). Most of them were teaching multiple subjects including mathematics (53%), science (47%), CS (30%), literacy/English (27%), all STEM disciplines (20%), and others (10%). These and other demographics are shown in Table 1, which express responses as a percentage of the total sample. In many cases, participants selected one or more answers and thus the sum of the percentages for any characteristic may add up to more than 100%.

Each cybersecurity microcredential iteration changed slightly based on the previous Cohort's suggestions (see Table 2). The cybersecurity microcredential consisted of a series of learning modules that covered the principles of cybersecurity (see Table 3), and each module contained clear learning objectives aligned with the Computer Science Teachers Association (CSTA) standards (https://www.csteachers.org/, accessed on 8 December 2021). The microcredential team created a variety of activities based on the CS and disciplinary standards. There were learning objectives within each module. Quantitatively, the researchers used a self-efficacy subscale survey (inspired by [32]) with 29 items to assess whether precollegiate teachers' beliefs towards CS changed or did not change. The teachers' beliefs surrounding CS were assessed on a scale from 0 to 5, where 0 was strongly disagree and 5 was strongly agree. Qualitatively, the researchers conducted semistructured interviews, transcribed the interviews, and coded for themes, while focusing on changes for microcredential improvement. Codes were determined using open (labeling of responses) and axial (connecting categories from the first step) coding. All participants signed a university approved Institutional Review Board (IRB) consent form to participate in the study.

Table 1. Demographics of combined microcredential Cohorts (n = 30).

Gender (n = 30)					
Female	73%			Male	27%
Subjects Taught (n = 30)					
Mathematics	53%	Science	47%	Computer Science	30%
Literacy/English	27%	STEM	20%	Other	10%
Levels Taught (n = 30)					
PreK–2	27%	3–5	37%	6–8	47%
9–12	37%	HE	3%		
Taken prior Cybersecurity Class/Course (n = 30)					
Yes	63%			No	37%
Years Teaching (Overall) (n = 30)					
0–3 years	7%	4–6 years	17%	7–10 years	10%
11–15 years	7%	16+ years	59%		
Years Teaching (CS) (n = 25)					
0–3 years	88%	4–6 years	12%	7–10 years	0%
11-15 years	0%	16+ years	0%		

Table 2. Summary of modules and features in Pilots 1, 2, and 3.

Component	Pilot 1	Pilot 2	Pilot 3
Modules	2	5	12
Required Modules: Details	2: Modules 0 and 1	3: Module 0 + Choose 2	3: Module 0 + Choose 2
Housed/Located	LMS/Canvas	LMS/Canvas	LMS/Canvas
Virtual Office Hours	2x/week—1hr slot	2x/week—1hr slot	By Request
Content Knowledge Quest.	No	Yes	Yes
Attitude Survey	No	Yes	Yes
Focus group & interviews	Yes	Yes	Yes
Bi-weekly progress reports	Yes	Yes	Yes
Duration	28 days	42 days	49 days
Participants	5	16	9
Resources	Custom resources and research materials.	More resources and research materials. Added sample lesson plans & computational thinking flashcards.	More resources, research materials, and sample lesson plans. Added design thinking flashcards and videos.

The first Cohort's engagement in microcredential Pilot 1 was 28 days long, the second Cohort in Pilot 2 was engaged for 42 days, and Cohort 3 worked for 49 days. Each module in the course was grouped and organized to allow for scaffolded information for participant teachers as they progressed through the course. If participant teachers were to complete the entire cybersecurity microcredential, after completing Modules 0 and 1, participant teachers would choose between Modules 2 and 3; the same is true for the groupings of Modules 4 and 5, as well as the final grouping of Modules 6 through 12.

Table 3. Modules offered throughout the three Pilot experiences.

Module	Pilot 1	Pilot 2	Pilot 3
0	Intro to Cybersecurity	Intro to Cybersecurity	Intro to Cybersecurity
1	CIA Triad	CIA Triad	CIA Triad
2		Abstraction	Abstraction
3		Modularity	Data Hiding
4		Least Privilege	Simplicity
5			Minimization
6			Modularity
7			Domain Separation
8			Least Privilege
9			Layering
10			Resource Encapsulation
11			Process Isolation

The team expected that cybersecurity content would increase with each successive Cohort and that changes would be made based on teacher participant feedback. Cohort 1 (i.e., Pilot 1) consisted of an introduction to cybersecurity and the CIA triad (confidentiality, integrity, and accessibility), while Cohort 2 (i.e., Pilot 2) added three new modules including abstraction, least privilege, and modularity, and then Cohort 3 (i.e., Pilot 3) added seven new modules including data hiding, simplicity, minimization, domain separation, layering, resource encapsulation, and process isolation. The participant teachers worked for 28 days (Cohort 1, n = 5, summer 2020), 42 days (Cohort 2, n = 16, fall 2020), and 49 days (Cohort 3, n = 9, summer 2021) to complete the course material. The start of each Cohort/Pilot was defined by an introductory Zoom session, while the end was defined by debriefing meetings and then semistructured interviews. The precollegiate teachers completed the microcredential at their own pace within these timeframes. Additionally, the 29-question survey was provided for the precollegiate teachers before, during, and after the microcredential modules for Cohorts 2 and 3 (but not Cohort 1). In Cohort 2, of the 16 participants, all of them completed the pretest (16/16; 100%), and 11 participants completed the post-test survey (11/16; 69%). In Cohort 3, of the nine participants, seven completed the pretest (7/9; 78%), and five participants completed the post-test survey (5/9; 56%). The semistructured interviews were conducted after the debrief Zoom session at the end of the microcredential Cohort/Pilot, when the precollegiate teachers met with an interviewer (team member) and an observer (main instructor). Over all three Cohorts, nineteen precollegiate teachers were interviewed (19/30; 63%), and each interview was conducted online via Zoom within an approximately 30-min time frame, transcribed, and then coded as part of the larger set of data.

5. Findings and Participant Learning

5.1. Quantitative Findings

Overall, for Cohorts 2 and 3, precollegiate teacher self-efficacy improved after taking the cybersecurity microcredential. The authors present the evidence of self-efficacy towards CS for the cybersecurity microcredential from survey Questions 11 and 12 (see Figures 1 and 2). Question 11 (Figure 1) asked the teacher participants to respond to the following prompt: "I can effectively teach all students computer science" [16]. On the presurvey (n = 22), 68% (15/22) of the precollegiate teachers responded 'strongly agree' and 'agree' about their self-efficacy to teach computer science effectively in the classroom. On the postsurvey, the agreement (strongly agree and agree) increased to 86% (12/14). Question 12 (see Figure 2) asked teacher participants to respond to the following prompt: "I can teach the computer science concepts required by the curriculum" [25]. On the presurvey, 68% (15/22) of the precollegiate teachers responded 'strongly agree' and 'agree' about their self-efficacy to teach effectively in the classroom. On the postsurvey, 86% (12/14) of the precollegiate teachers responded 'strongly agree' and 'agree'.

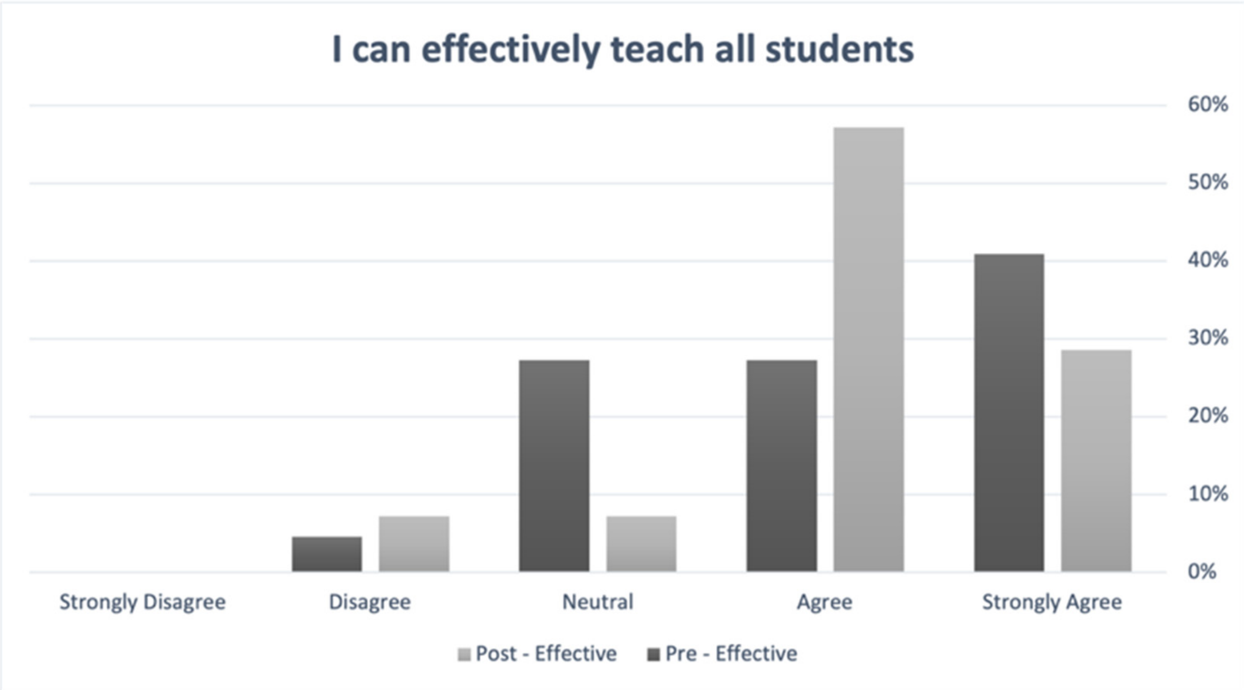

Figure 1. Question 11 from the self-efficacy survey, "I can effectively teach all students computer science".

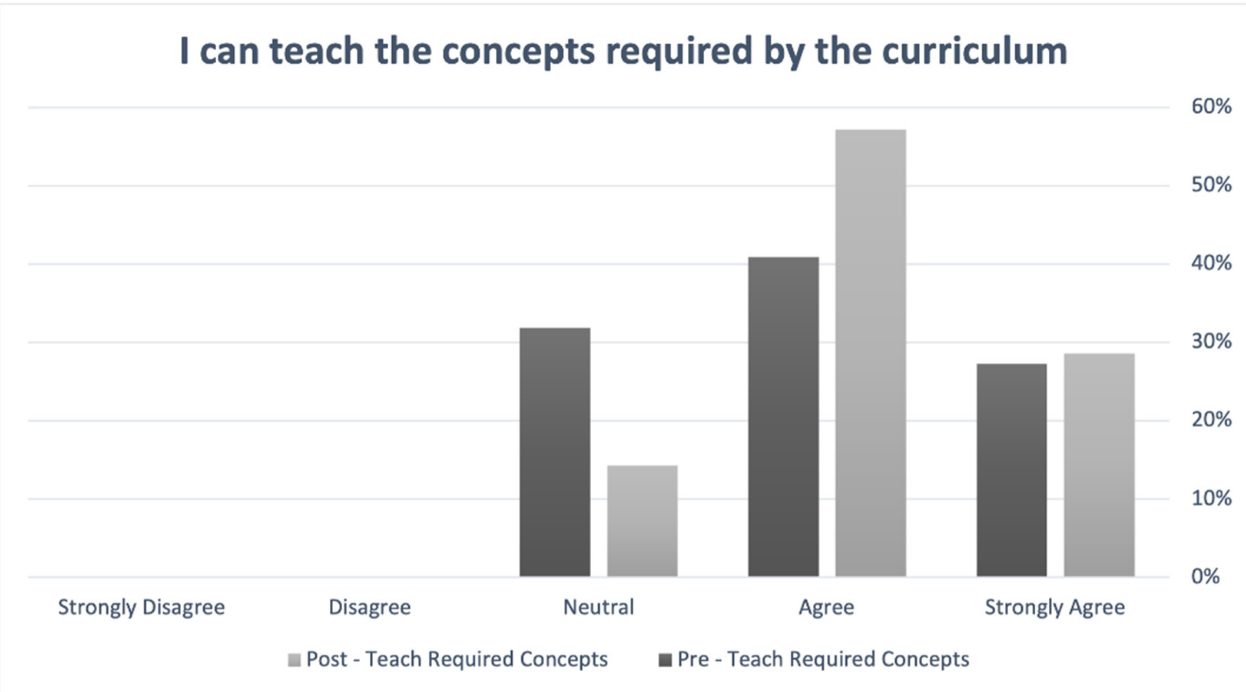

Figure 2. Question 12 from the self-efficacy survey, "I can teach the concepts required by the curriculum".

The time spent in the learning management system (LMS) for the microcredential varied widely. The LMS biweekly progress reports also showed self-reported use as varying widely (see Figure 3). The most time spent by a participant in the LMS was 192 h and least time spent was 2 h. The average time spent on the three modules was about 40 h. From the self-reported biweekly progress reports, the most time spent was 40 h and the least time spent was 6 h. The average time spent on the three modules was about 14 h. Given the drastic discrepancy between the maximum LMS reported time (192 h) and the corresponding self-reported progress report time (40 h), it is likely that a browser issue caused a session to remain open and inflate the time recorded by the LMS. This outlier was removed prior to any correlation analysis. Additionally, there was a weak, positive relationship between English/literacy teachers or high school educators and using the microcredential resources (including the LMS itself) for more time. Female teachers or STEM teachers were less likely to use the resources for long periods of time (or were more likely to use it for shorter durations).

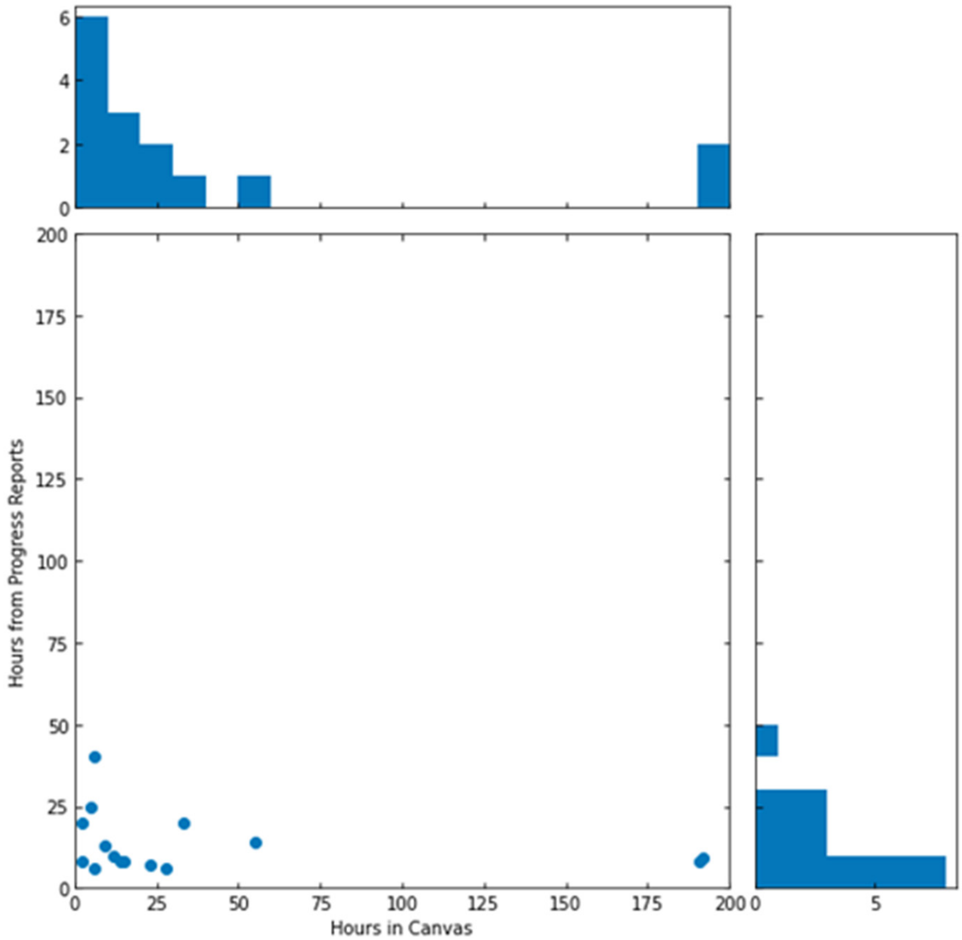

Figure 3. Time spent in the Canvas LMS (hours) versus time reported in biweekly progress report (hours). Note the outlier LMS reported time which was likely caused by a browser/LMS issue.

Importantly, there was a purposeful integration of disciplines and content, and some of the cybersecurity principles overlapped with computer programming and computational thinking concepts such as abstraction and modularity [17–22]. Therefore, the CS teachers who had prior programming knowledge spent less time than the STEM teachers who had never taken a programming course or had no prior programming knowledge. All precollegiate teachers took the introduction to cybersecurity module (Module 0), and this was included in the time spent by each participant. In addition, the precollegiate teachers were given the choice of which follow-on module to complete (Figure 4); 29% of the teachers chose the abstraction module, while only 2% of the teachers chose the minimization module.

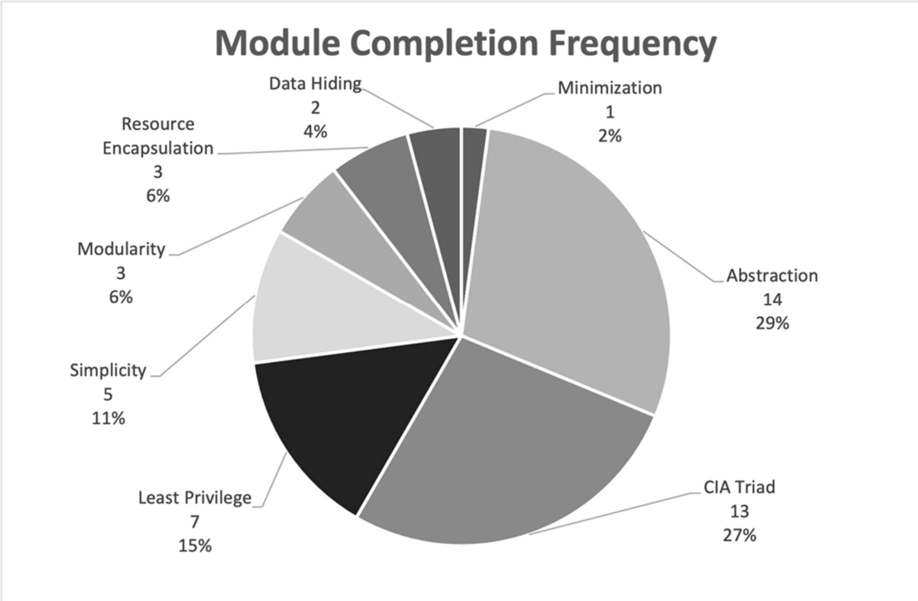

Figure 4. Modules selected and completed (n = 48).

5.2. Qualitative Findings

Overall, the authors conducted nineteen interviews over the three Cohorts. In coding the responses, two main themes surfaced. One was "Resources", and the second theme was "Implementation". Each main theme showed two subthemes, and these are described with examples in the following paragraphs.

For the main theme "Resources", the subthemes of "resources offered" and "resources used" were discovered. In the "resources offered" subtheme, the teachers most often referenced the flexibility to complete the microcredential in their own timeframe, community building, and the office hours.

For flexibility, one teacher commented, "microcredentialing was done at more of our own pace" (participant Cohort 1), and, "I like the flexibility to be able to do it whenever, it worked for me" (participant Cohort 2).

For community building, a teacher said, "I'm the only teacher, so it's really nice to make these connections and to talk with people, and [to] hear that I need to [use] computational thinking [explicitly in my classroom]" (participant Cohort 2). Another teacher commented, "I like the relationships … and getting to know [the teachers and microcredential team]" (participant Cohort 3).

For the office hours, the precollegiate teachers found the synchronous virtual office hour provided by the microcredential team beneficial, but the hours were not used frequently or by all participants. One participant plainly stated, " … The office hours were really nice … " (participant Cohort 1), while others alluded to the fact that they were not used.

In the subtheme "resources used", the teachers referenced the videos, lesson plans, and flashcards most often. For the videos, teachers made comments such as, "The videos were where I took most of my information from, the short articles, [and] the websites" (participant Cohort 1). Another teacher said, "I felt like that [the videos] helped just solidify the understanding that I came to in the course" (participant Cohort 1). The videos were often referred to as better than other resources, such as, " … the technical material, I read it, but it wasn't as engaging to me as the video was" (participant Cohort 1). Another participant said, "I felt that there was a good variety of ways that the information was distributed, both in text and in video. So, the video choices were very good, I thought the video choices were excellent, actually" (participant Cohort 1). For the lesson plans, one teacher, stating what others summarized, said, "I love the ideas of lesson plans. I love the ideas of writing good, solid lesson plans. I think it has to be one of those things [where you can] choose to write [the lesson plan], maybe just with a list of please include the following things in your lesson plan" (participant Cohort 1). This trend continued in Cohort 2, as explained by one teacher: "it was nice that [the lesson plan] was something that you could actually, like, use in class" (participant Cohort 2). For the flashcards, one teacher, echoing what others also stated, said that the flashcards were "a nice, tactile thing that I could use to actually hold in my hands . . . I appreciate flashcards" (participant Cohort 1). Another teacher said, "I like flipping through flashcards [and learning the content]" (participant Cohort 1), while a third stated, "I had a basic knowledge, but now I have some actual, like, terminology that goes with it" (participant Cohort 3). Others thought that the flashcards were too traditional and an outdated teaching tool.

For the main theme "Implementation", the subthemes of "implementation in the classroom " and "implementation of the next microcredential" were discovered. For the subtheme "implementation in the classroom", the teacher participants expressed a desire for materials/resources that were ready to reuse without modification. One teacher commented, " . . . I like when things are directly applicable, because then I can just push them into my classroom . . . " (participant Cohort 1). Another teacher stated, "I especially liked the unplugged activities . . . it's always a good idea to have those types of things that bring it to such a concrete level to your students . . . I would suggest you add more of them in." One teacher "felt like [the microcredential] was really interesting, [not] cookie cutter, and what I could actually implement into my classroom" (participant Cohort 3). Regarding using the flashcards in the classroom, one teacher said, "I think that the most valuable [aspect] was that . . . the information from the flashcards, or even the flashcards themselves, . . . could be used in the classroom . . . " (participant Cohort 1). Other teachers pointed out that they needed more background information to create quality products for their classrooms. For example, one teacher said that the lesson plan that they created "didn't have many higher-level thinking skills [in it], but I didn't necessarily . . . have the content [knowledge to do that well at the time]" (participant Cohort 2). The majority of the teachers said something like, " . . . I always like things that I can, like, take and use specifically in my classroom" (participant Cohort 2). Some of those teachers went on, mentioning specific pieces that they would use in the classrooms, such as, "I especially liked the unplugged activities because I just think it's always a good idea to have those types of things that bring it to such a concrete level to your students" (participant Cohort 2).

In the "implementation of the next microcredential" subtheme, the teachers pointed to resource use, either ways to increase the use of what was offered or to add different resources. For example, one precollegiate teacher stated, "I would suggest maybe just [adding] some samples for teachers in the grade-band areas . . . you could say okay, if you are teaching K-2 this might be an appropriate activity, if you are teaching 6–8, if you picked a K-2 activity, this is how you would ramp it up . . . ". Another Cohort 1 teacher commented, "I think if there could be either videos or, like, an instructor presenting, I'm a really traditional, like, learner . . . you could do a video of yourself teaching the concept and taping it—just, like, [add] a short video".

Another set of teachers wanted to see more direct connections to STEM content. One of them summed this up when stating, "if you could find some of these ideas that tied into, like, a science class or math class, I would think that would be very helpful for teachers because, like, as a teacher you're always so worried about your own content, [and] it's hard to balance bringing [any] extra activities in [like cybersecurity content on its own]" (participant Cohort 2).

The teachers were forthcoming about what modules challenged them and what to improve. For example, "I just didn't know, like, a ton about the modularity [piece]. I had heard the word, but I gained a lot of knowledge on that. And I really struggled with the whole idea of abstraction, like, I get it, but I couldn't explain it. So, I had to go through a few things to . . . break it down [maybe you could assist with this]" (participant Cohort 2).

The qualitative findings showcase the continued interest in the teacher resources presented in the microcredential and how they could be used for classroom implementation.

As summarized in Figure 5, the "Resource" theme had marked areas for "resources offered" and "resources used", while the "Implementation" theme had the distinct subthemes of "implementation of the next microcredential" and "implementation in the classroom".

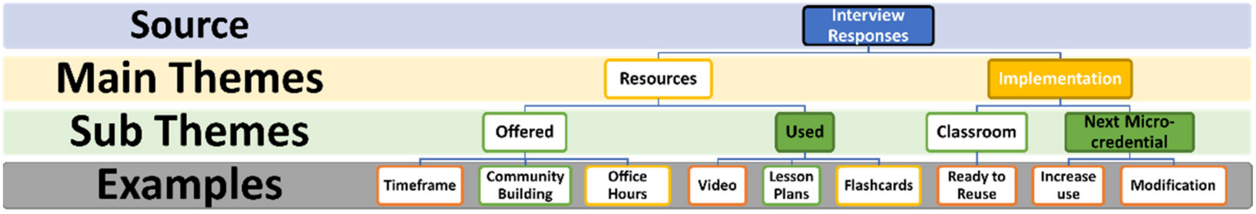

Figure 5. Representation of main themes and subthemes with examples.

6. Conclusions and Contributions to STEM Education

Overall, in relation to how the cybersecurity microcredential impacts precollegiate teachers' computer science self-efficacy (the first research question), the microcredential seemed to increase the teacher participants' self-efficacy regarding teaching all students computer science. The teachers also used concepts required by the CS curriculum. In the survey as well as the interviews, the teacher participants showcased their belief that they could teach cybersecurity concepts in their courses (both STEM and CS). Knowing that teachers gain confidence in teaching cybersecurity concepts after a shorter-duration microcredential is in line with the Dunning–Kruger effect [33], where people overestimate their knowledge and skill set, then struggle with the content/skills and with continued work find a place of actual use for the content/skills. Teachers taking the cybersecurity microcredential would most likely need support for the sustainable use of the content.

The second research question focused on the amount of time that precollegiate teachers spent in the microcredential, and the amount of time spent by any teacher varied drastically. There was a weak, positive relationship between the English/literacy teachers and the use of the microcredential resources for more overall time. The English/literacy group utilizing the resources for more time could speak to the potential need for English/literacy teachers to explore and understand a domain outside of their usual expertise. While high school educators might have spent more time with the resources because they were more relevant to classroom implementation, this was not explicitly asked or addressed. Conversely, STEM teachers were less likely to use the resources for long periods of time, and this could be related to teaching precollegiate students in the middle of their studies before college begins (as many of the STEM teachers taught at this level). Interestingly, these science and STEM teachers were more likely to have more overall self-reported biweekly hours (or total hours spent) but were shown to have less LMS/resource hours.

Regarding how the precollegiate teachers shaped the microcredential to be more effective (the third research question), the teachers focused on the resources and the implementation (for themselves and for their future students) to improve the microcredential. Additionally, as stated earlier, an online PD study (which is similar to a cybersecurity microcredential) showed that the areas in need of attention included matching PDs to the teachers' backgrounds, aligning the PD with curricula, and using motivational design to enhance teacher engagement [26]. The authors of this article agree with these areas of attention for PDs and add that a focus on the teacher resources should be offered with considerations for future classroom use as well as the implementation factors (for both the microcredential parts and for future students). These areas of attention are also warranted when creating microcredentials. In the three Cohorts, there were more female teachers participating (n = 22) than male teachers (n = 8), which follows the current overall teacher demographics; however, the situation is flipped in current precollegiate CS teacher trends, which are still dominated by males.

Since the participant teachers were either STEM or CS teachers, these findings can help guide those creating other microcredentials, PDs, or content resources. The authors argue that focusing on how to develop meaningful, specialized-content microcredentials for educators will only become more important. Notably, the intervention of a cybersecurity microcredential increased the self-efficacy of precollegiate teachers toward CS, as has been shown in other disciplines [21]. The results illustrate that resources such as sample lesson plans, activities such as flashcards, and mentoring in office hours impacted precollegiate teachers' self-efficacy toward CS, allowed them to create materials for future classroom use (or implementation), and gave them space to voice an opinion on what was or was not functioning to motivate them in engaging with the microcredential. Moreover, the identified resources and implementation pieces assisted the teachers in making the connections between cybersecurity and their disciplinary subject area, as explained in the interviews about future cybersecurity classroom lessons.

Although not part of this study, an informal follow-up email asked the participants about the classroom use of the lesson plans that they created during the microcredential. Based on the responses, at least 46% (14/30) self-reported that they used the cybersecurity lessons they created. Thus, after the microcredential, almost half of the precollegiate teachers (across a variety of disciplines) were able to introduce computer science/cybersecurity unplugged activities and lesson plans into instruction without using any specialized technological devices.

One of the study's successes was that the majority of the precollegiate teachers believed that they had an ability to teach the computer science and cybersecurity content in their classroom when they had resources provided, especially when they could be immediately used in the classroom. On the other hand, one of the main challenges was creating the right balance of resources to teacher activity for engagement, reflection, and potential classroom implementation. The teacher participants seemed to prefer shorter readings, videos, and go-to classroom resources.

Our recommendations for creating a computer science or cybersecurity microcredential include:

1. Follow prior recommendations in the literature for online PDs and microcredentials, such as matching PDs to teachers' backgrounds, aligning the PD with curricula, and using motivational design to enhance teacher engagement [20].
2. Focus on creating teacher resources that could be offered to a middle or high school STEM or CS classroom audience, so that the teachers have to make less modifications for use. This includes novice, intermediate, and advanced resources.
3. Use resources (such as journal articles and flashcards) that include sample computer-science- or cybersecurity-related unplugged and plugged activities, showing that computer science is more than coding and involves problem-solving. Use shorter readings and videos when possible.
4. Identify for the teachers where classroom implementation could be beneficial for students to make disciplinary connections in and beyond STEM.
5. Offer support to teachers for classroom implementation, beyond asynchronous support such as email. If traveling to the location is not feasible, then synchronous engagement offers a stronger assistance for sustainable use.

7. Limitations, Future Research, and Implications

The main limitation of this work is the number of teacher participants (n = 30) across the three Cohorts/Pilots. Additionally, since the purpose of the Pilots was to create a stronger cybersecurity microcredential, all three Pilots differed in some way, affecting the data collection consistency. Another limitation is a lack of previous research studies on microcredentials and, in particular, on the cybersecurity education field. Prior related research studies seem limited and need further data collection on developing, implementing, and evaluating high-quality microcredentials. The results of this study demonstrate that the cybersecurity self-efficacy increased, the time spent on microcredentials varied, and the teachers wanted to be able to use resources and then implement what was learned. Future research could focus on a more in-depth analysis of the teacher responses in both quantitative and qualitative measures. Additionally, as a future improvement, the team plans a final study that corroborates the modifications presented for success. Another question to explore is whether a microcredential can be tailored based on the demographic information of the participants. Since some precollegiate teachers used diagrams demonstrating computational thinking steps in their lesson plans (decomposition, abstraction, pattern recognition, algorithm design, evaluation, and logic) the connection between computer science, cybersecurity, and computational thinking might be another area ripe for exploration.

As the authors of this article believe that precollegiate teachers should utilize cybersecurity principles and concepts in their classroom (regardless of their subject area, background knowledge, or interest) the implications of this work extend to those creating microcredentials, PDs, teaching at any level, and involved in policy surrounding teaching certification and licensure. All stakeholders should be partners in creating microcredentials and resources, as they hold the key to influencing others to realize that computer science and cybersecurity go beyond coding, and that what the teachers need is an important aspect of what should be created for them.

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