Towards Incorporating Computational Thinking Skills Across the Curriculum

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Abstract - This research-to-practice full paper describes K-12 Diversity and Broadening Participation through the integration of Computational Thinking (CT) across the curriculum. CT is implicit within the current high school curriculum and used by teachers and students every day in their classrooms across multiple content areas. Most students are unaware they are using these skills and that these skills are the foundation of learning computer science. Over a series of workshops, high school teachers and students, and university faculty discussed the need to incorporate CT skills throughout the high school curriculum to improve those skills in students and to impart a better understanding of computer science. The result was a guide created to assist high school teachers to make CT concepts explicit in their classes. A main component of the guide includes specific examples of how to incorporate CT skills in various content areas. The guide was created on a foundation of cultural relevance and cogenerative dialogues. Here we describe salient points about the creation of the guide and insights gained during these workshops.

Keywords – computational thinking, diversity, inclusivity, underrepresentation, k-12, preconceptions

I. Background

This research-to-practice endeavor is part of a larger NSF-funded project entitled "Cogenerative Development of Culturally Relevant Pedagogical Guidelines for Computer Science and Computational Thinking in High Schools." During Year One of the project, qualitative semi-structured interviews were conducted with 26 high school students to better understand the challenges and barriers to enrollment, engagement, and success in Computer Science courses in high school. The study concluded [3] "If existing stereotypes dominate our culture about what Computer Science is and what a Computer Scientist looks like, it makes sense that underrepresented individuals such as those identifying as female and underrepresented racial/ethnic groups in Computer Science do not choose these classes and ultimately CS or IT careers. Breaking these stereotypes through ... changing the face of computer scientists, as well as improved curriculum are all steps to breaking down the perceived barriers that keep underrepresented students out of Computer Science."

Based on the need to improve the curriculum, Year Two of the project focused on providing guidance to non-computer science teachers on how to facilitate the integration of CT skills to multiple content areas and make computer science instruction more engaging and relevant to students' experiences and realities. This paper focuses on Year Two and the creation of the Guide over a series of workshops and the pilot implementation of the Guide.

Year Three of the project will focus on collecting and analyzing the data generated during the implementation and evaluation of selected CT skills and learning pursuits incorporated by teachers using the Guide.

II. Introduction

[6] conducted an extensive review of the literature on CT in education and concluded CT does not have a standard definition in the literature. The working definition used here is from [6] "The conceptual foundation required to solve problems effectively and efficiently (i.e., algorithmically, with or without the assistance of computers) with solutions that are reusable in different contexts." An interesting aspect of this definition is that CT need not require the assistance of computers. Indeed, solving problems effectively and efficiently is certainly encountered in high school mathematics education. But CT skills go beyond mathematics and computer science and are implicitly encountered in other content areas.

Here we describe the development of The Guide [7] that can assist high school teachers to explicitly identify and label CT skills in their existing class content. That is, teachers are already covering CT concepts, but may not recognize them as such. The Guide was developed over six day-long workshops during the 2022-2023 academic year. Participants included university faculty, high school teachers from multiple disciplines, under-represented high school students, and high school administrators. The workshop activities were rooted in cultural relevance and cogenerative dialogues.

Cultural relevance is important for the Guide as one goal of the project was recruitment and retention of traditionally under-represented students in computer science, where the majority is white and Asian males. As stated by Christopher Emdin, "We cannot just make things pink for girls or call a project 'urban' to reach students of color." [2]. Gholdy Muhammad's learning pursuits [4] were used as the basis to incorporate cultural relevance into the Guide. The learning pursuits are: (1) identity development, (2) skill development, (3) intellectual development, (4) criticality, and (5) joy. Skill and intellectual development are a mainstay in academic classes; therefore, this project focused on identity, criticality, and joy.

Cogenerative dialogues, or cogens, are structured conversations between a teacher and a subset of students that typically occur outside the classroom. The goal of cogens is to improve the learning environment; teachers gain an understanding about how their students can make sense of the classroom and students gain awareness that their thoughts and opinions are valued [1]. All group activities during the workshops followed the protocols of successful cogens [1]: (1) participants being positioned in a circle, (2) ensuring that there are equal opportunities for all participants to share, (3) no one voice, particularly that of the teacher, being privileged over another, (4) affirming the experiences of all participants, and (5) listening attentively and allowing the speaker to complete their thoughts before responding. By following these protocols, all voices and perspectives were considered in the development process of the Guide.

Based on experience teaching computer science to college students and the comprehensive literature review on the topic [6], the CT skills selected for this project are listed below. Note that some of the skills are specific instances of more general skills, which are listed in parentheses.

1. **Decomposition**: The process of breaking down a complex task into smaller pieces to solve it.
2. **Algorithmic Design** (Algorithms): The process of creating a step-by-step plan to solve a complex problem.
3. **Algorithmic Efficiency** (Algorithms): The revising of a plan to solve a complex problem to be more efficient.
4. **Data Collection and Analysis** (Abstraction): The process of gathering data from relevant sources to better understand a complex problem.
5. **Pattern Recognition and Sorting** (Abstraction): The process of finding and organizing patterns across data to better understand a complex problem.
6. **Modeling** (Abstraction): The process of using graphs and pictures to describe a complex problem.
7. **Iteration and Searching**: The process of gathering information (ex. through peer feedback) to modify one's approach for solving a complex problem.
8. **Debugging and Problem Solving**: The process of locating an error and creating a solution for when something goes wrong in a complex problem.
9. **Generalization**: The process of finding common aspects or connections between two different problems.

The following sections describe the importance of these skills across the curriculum, provide example lessons/activities involving these skills, "aha" moments encountered during the workshops, and the plan to implement and evaluate these skills in a classroom environment.

III. Importance of CT Across the Curriculum

CT skills are used by teachers and students every day in their classrooms across multiple content areas:

- Breaking a recipe into its individual steps (decomposition)
- Creating a timeline for the sequence of events leading up to WWI (algorithmic design)
- Collecting demographic data for the past five Congresses and determining the number of each party, of each gender, of each ethnicity (data collection and analysis)
- Identifying different parts of sentence structure (pattern recognition)
- Plotting a graph of demographic data from past Congresses (data modeling)
- Practicing learning a piece of music, again and again (iteration)

- Fixing a draft of a persuasive essay (debugging and problem solving)
- Identifying the common theme among five different pieces of writing (generalization)

Most students are unaware they are using these skills. More importantly, they are unaware these are the skills that are the foundation of learning computer science. As [8] noted "Computational thinking is a fundamental skill for everyone… we should add computational thinking to every child's analytical ability." The goal is to shift students' perspective from "*learn to think like a scientist*" to "*you already think like a scientist, here's how.*" By being made aware of their capability to think like a scientist and understand foundational computer science concepts, ideally, more students will have the confidence to enroll in high school computer science courses and pursue careers in computer science. Another benefit is promoting computer science as interdisciplinary is students can combine their love of one content area with computer science. For example, data analysis of historical events, problem solving across cultural differences, etc.

For teachers, an important note for adding CT across the curriculum does not mean adding new or additional content to the curriculum. The Guide provides a template for adding specific CT language to existing lesson plans. This template helps to recognize the skill, name it explicitly, make it visible to the students, and highlight its use within the lesson and lesson activities. Examples are provided for many content areas including social studies, math, ELA, science, arts, and music – as well as computer science. This requires a review of existing lesson plans with a lens focused on CT skills. To guide teachers, the Template was created with prompts for adding CT skills to lessons including:

- Student Identity: Who are the students in your class? What are their cultural backgrounds?
- Outcome: What content and/or skill(s) will the student learn?
- Assessment: How will you know if your students have successfully applied / learned the CT skill?
- Instruction: What specific instructional approach(es) will you use to connect the CT skill to the content / topic? What will the lesson / activity / assignment look like?
- Alignment: How is this activity / lesson / assignment related to the selected CT skill? How will students practice the selected CT skill?
- Computer Science Aspirations: How will this activity/lesson/assignment help students do computer science in the future? How will the connection between this content area and computer science be made explicit to the students?

By hearing the same CT skills language repeated across multiple content areas and multiple lessons, students will increase their awareness and use of CT skills. Eventually students internalize the language and skills and can apply them throughout the content areas thereby expanding the application of CT skills beyond the classroom.

IV. Example Lessons and Activities from the Workshops

Participants actively engaged in (not just attended) six workshops. Participants included three PIs, six high school teachers, six high school students, two independent consultants, two university faculty, three researchers, and two research assistants. There was a mix of computer science and non-computer science participants. Workshops were held monthly on Saturdays 9AM to 4PM and participants were kept motivated by good food, cogenerative dialogues and a variety of activities. Each workshop peeled back another layer on CT and cultural relevance, building on common experiences and leading participants to think more deeply about teaching, learning, and community.

To provide participants with the underlying perspective scope, they were introduced to cogenerative dialogues and culturally relevant pedagogy before working to identify CT skills in multiple content areas. Chris Emdin [1] led a discussion on "What are cogenerative dialogues (cogens) and how can we use them to foster democratic participation?" and the need for students to be intellectually challenged and have a shared experience around ability, language, values – the entire classroom culture. After this thought-provoking discussion, participants broke into small groups to discuss the use of cogens to accomplish workshop goals, what it means to be "culturally relevant," and identify specific practices that make students withdraw or engage. In addition, Gholdy Muhammad [5] introduced culturally relevant pedagogy and curriculum. Gholdy asked participants to think about cultivating students' identity: Who are your students? Who do others say they are? Who do they desire to be? And students asking, "What does this curriculum have to do with my life? "

After the background discussions on cogens and culturally relevant pedagogy, participants used the Template, designed as part of the Guide, as a vehicle to create and edit their lesson plans to integrate CT skills. The Template is dual purpose to be used by both content area teachers when revising lesson plans to explicitly incorporate CT skills, and by computer science teachers to assist them in using culturally relevant perspectives in their lessons.

With an understanding of cogens and culturally relevant pedagogy, participants worked to apply CT skills to math and science content. For each CT skill, participants identified problems to solve, things to do (activities) and how to adjust for cultural relevance. One group discussed a lesson on determining the ideal way to drive to the mall as a CT skill. When they took a second look through the lens of cultural relevance, participants realized some students may not have access to a car and would need to use public transportation and needed to adjust the language and examples in the lesson. Participants continued to identify CT skills in English Language Arts, Social Studies, and Art/Music. Again, for each CT skill, participants identified the problem to solve, the activities, and how to modify for cultural relevance. For social studies and ELA, examples of CT skills included writing multiple drafts of an essay (iteration) to researching, identifying, and deterring racial profiling. Multiple lesson plans using the Template were created for each content area.

Participants also identified perceptions and beliefs about computer science, the challenges of underrepresented students in CS / STEM and how to counteract / reduce those challenges. Ideas included shared decision making and identifying students' expectations. Participants identified the parts of their identity seen in the CS curriculum and what brings them joy in the classroom. To get to culturally relevant problems, participants focused on investigating and learning more about local community topics because by using examples from the local community students are more invested in solving the problems.

Later workshops gave specific focus to CT skills in CS. Using a typical introductory CS program problem statement, participants applied the Template and culturally relevant pedagogy. Participants worked on CT in CS looking at particularly difficult CS concepts, such as arrays, and identifying how to better understand student identity within these concept lessons. Student participants focused on incorporating the students' perspectives into the classroom and recommendations for having their voices heard. Questions included "why is this important to me?" and "how will this topic help students to know, validate and celebrate who they are?" [5, p 69] and allow the students to learn something about themselves. Using specific CS topics, students identified activities and lessons to enhance student engagement and bring joy. The result was multiple examples utilizing the Template identifying CT skills in multiple content areas.

V. Aha Moments

One of highlights of the workshops for this project was the "aha moments" experienced by the students and teachers. One of the PIs for the grant, a sociology professor, along with two undergraduate research assistants, took field notes during the workshops. These field notes, as well as participant survey responses, were reviewed to assemble a summary of the meaningful "aha moments." These "aha moments" primarily included the participants' reflections when they realized the application and/or significance of the work being done for incorporating CT skills into their lesson planning.

As the workshops progressed, the students began to recognize the many challenges teachers face in planning daily lessons. Students commented they were not aware how much time and effort teachers put into their lessons and how passionate their teachers were about teaching. Students appreciated this awareness. Another revelation from the students was learning about the teachers' personal lives as the teachers shared their interests, daily lives, and other things outside of class material. One student participant commented "connecting with students on a personal level, such as small group sessions, humanizes both students and teachers to each other."

One "aha moment" that really stood out was watching a social studies teacher progressing through the workshops. During the early workshops, this teacher was really grappling with why they were selected to participate in this project. The teacher just couldn't understand how CT skills were applicable to social studies or why it was even necessary. This teacher was a master teacher! They were a veteran teacher with many years of experience; they had been quite successful in getting the students engaged. During the fourth workshop, this teacher was describing a product of their small group activity, which was the start of a social studies lesson using a CT skill. The teacher said, "I get this," as they began to understand how and why CT skills could be applied in social studies lessons / activities. It was a thrill to see that change in attitude and understanding of the need for this type of work in schools. This participant continued to evolve with CT skills and became an exemplar for this project.

Each workshop included large group discussions and small group sessions. During one small group activity in the final workshop, one group was discussing sample computer code. A social science teacher did not understand and was asking clarifying questions. At one point the teacher exclaimed "I'm learning so much!" A computer science teacher showed some sample code on their laptop and asked the same social science teacher to add some code. The social science teacher's reaction, as they were writing code, was "This is so cool!" This was an excellent example of how an individual not familiar with computer science was made to feel comfortable by the computer science experts in the group, and how the non-computer science participants were able to learn and better understand computer science and the goal of the project.

The importance of taking field notes and recording the participants' reflections throughout the workshops has been invaluable for this project. The collaboration protocols and opportunities for all participants to work and socialize together carved out an equitable and unique environment in which all participants could empathize with multiple perspectives for teaching and learning. The reporting on the evolution of the participants' understanding of CT skills and how students internalize and make sense of these skills across all disciplines provided many bonus insights into building the Guide for the benefit of future educators.

VI. Next Steps: Implementation and Evaluation of Selected CT Skills

After working for a year developing the Guide, teachers were asked to implement it by utilizing the Template for an activity in their class. The Template was developed during the workshops to help teachers incorporate CT skills and learning pursuits into their class. Nine teachers were identified to implement the Guide during Year Three of the grant, three from each of the partner schools with one being a computer science teacher, one from another STEM area and one from the humanities / social sciences / arts. Five of these teachers were participants during the workshops.

The teachers were asked to incorporate the CT skills and learning pursuits, specifically student identity, joy, and criticality, into at least three activities each half of the school year. The activity may be any aspect of their class, such as a lesson, portion of a lesson, in-class exercise, or homework assignment. Understanding the demands on schoolteachers, the intent was to understand challenges for underrepresented students in computer science, to recruit more and retain existing students in the computer science classes, and not add too much additional work for the teachers. It was stressed throughout this project that the teachers' curriculum would not change; simply how some of the content was delivered to the students.

For each activity, the teacher was asked to submit the Template, which includes the following items: CT skill(s) incorporated into the activity, student demographics, activity outcomes, instructional aspects, assessment, alignment with the CT skill(s), application of the learning pursuits (identity, joy, and civic engagement), and how the activity relates to computer science. The teacher was also asked to submit a reflection after completion of the activity by responding to Template Reflection Questions (TRQ). The grant PIs provided timely feedback on both the Template and TRQ to allow the teacher to adjust future activities utilizing the Template.

The participating teachers conducted a pretest with their students in each class they intended to incorporate the Template. At the conclusion of the course, the teacher will administer a post-test. The results of the pre- and post-tests will be analyzed to determine the effectiveness of incorporating CT skills and selected learning pursuits in various high school classes to help recruit and retain students in computer science.

As teachers submit Templates and TRQ, the PIs review them, primarily looking for proper completion and areas where the teacher may need assistance. It is critical that all teachers utilize the Template for consistency in implementation and evaluation. The CT skills utilized will be analyzed looking for patterns, primarily to see if there are any CT skills heavily utilized and if there are any not being incorporated into activities. Analysis of the learning pursuits will also be completed because the preliminary findings indicated some students do not pursue computer science because they do not identify with that field of study. One goal of utilizing the Template is to bring student identity and joy to the activities with the goal of having more students enjoying computer science and seeing that as a possible career pursuit for them. The TRQ from the teachers allows the PIs to understand the effect of utilizing the Template. These will be analyzed so the Template can be modified, if necessary, to make it more practical for teachers.

The primary work beyond Year Three is to update the Guide and the Template based on the nine implementing teachers' reflection and feedback. The intent is to refine both documents for wider distribution. A website was developed for the project that includes the Guide and the Template for teachers to download. Other items hosted on the web site are example activities for various disciplines and several posters about the CT skills that were created for teachers' classrooms.

The other primary work beyond year Three is to analyze the selected CT skills based on the data provided by the implementing teachers. Each CT skill will be evaluated based on the usage by the teachers and teacher feedback. be a discussion about each CT skill's effectiveness to determine if each skill should remain or if any should be modified or removed from the list of CT skills to be emphasized in non-CS classrooms.

VII. Conclusion

The primary goal of this project is to recruit and retain more students in computer science, with a focus on under-represented students. We described how the Guide was created in Year Two to assist high school teachers to make CT concepts explicit in their classes to introduce all students to computer science concepts. The Guide was created on a foundation of cultural relevance and cogenerative dialogues to allow more focus on student voice and the concepts that get students excited about learning. This work has also impacted the participating teachers. One teacher reflected how this project has reinvigorated them as they are again excited by the act of teaching because this project allowed them to find new ways to be innovative. More details about everything presented here is in The Guide itself [7].

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