Collective Argumentation: Integration of Coding into Mathematics and Science Learning

Introduction

This project, titled **C**ollective **A**rgumentation **L**earning and **C**oding (**CALC**), is based on our belief that if teachers had an instructional approach that allowed them to teach coding alongside mathematics and science in integrated ways, then coding would become a mainstream subject taught in the elementary school curriculum. However, few practicing elementary school teachers have the academic backgrounds that allow them to teach coding in a manner that goes beyond allowing students to learn how to code through trial-and-error experimentation and as an additive learning activity such as an after-school program. Current content and practice standards call for the use of argumentation in the teaching of mathematics and science [1] [2]. This project is focused on extending collective argumentation framework developed by Conner [3] for the teaching of mathematics to the teaching of coding. Teachers at our partnering school district have completed the first design of a prototype CALC course where they used collective argumentation to learn how to code educational robotics. At the end of this course, the teachers developed lesson plans that were implemented in grades 3, 4 and 5.

This paper and conference presentation focuses on our research question, *how do elementary school teachers use the CALC approach to support their students' learning of coding, mathematics, and science content and practices?* While this paper provides preliminary results of this work, an in-depth analysis should be available at the conference presentation.

Framework of the CALC Approach

Collective argumentation [4] is the foundation for the CALC approach. As a learning strategy used in multiple fields of education, collective argumentation supports the student's ability to articulate the reason for approaching a problem in a particular way, justify her/his approach by using information and reasoning and provide the principles that establish that justification. When analyzing the students' collective argument, teachers identify three core elements called the claim, data, and warrant. The claim is the statement or statements whose validity is being established. The data are statements provided as support for the claims. The warrants are statements that connect the data to the claim(s). Collective argumentation supports student-to-student or teacher-to-student discussions and allows one to trace her/his understanding of ideas and concepts as they form. While the content within the claim, data, warrant, and other components is discipline-dependent, the interaction of among these elements is discipline-independent. Therefore, collective argumentation can be conducted across a variety of education disciplines making this process an excellent choice for teaching coding alongside the teaching of mathematics and science [5]. Our team believes argumentation-based coding will move elementary school students from novice programmers who tend to use a trial-and-error approach when learning how to code to the use of logical reasoning of why they used a particular coding structure. Figure 1 shows how we envision the CALC learning approach is applied.

The CALC Course

Fourteen teachers from our partnering school district enrolled in the prototype CALC course (outlined below). The teachers came from schools that followed different approaches for implementing the elementary school curriculum, represented different communities and treated STEM learning differently (e.g., STEM-specialist versus traditional elementary school teacher who taught all subjects). The teachers had a wide range of prior knowledge and experience with coding and robotics. Six teachers completed educational robotic workshops within two years of this course, and the other 8 had little or no coding background. Two of the teachers were media or STEM specialist, and one taught an English-as-a-Second-Language set of students. This range of teachers' prior knowledge of robotics and coding as well as their responsibilities and school environments created a challenging learning environment for the CALC course.

The CALC course was modified from an existing graduate-level course, ETES 6030 Robotics for Teachers. The objective of ETES 6030 course is to prepare teachers to teach educational robotics with course content focused on controllers, sensors, actuators, and programming logic. Course material examined sequential, repetition, and selection control structures. Applied activities involved the integration of robotics into mathematics and science as well as English language arts, and social studies. ETES 6030 does not have *the application of argumentation* as a learning objective. The first time the prototype CALC course was taught, the instructors modified ETES 6030 to include argumentation. The second time the CALC course was taught (2019 spring semester), new course material was added. This new material was based on feedback from the participating teachers, the research team collecting and analyzing the data and other sources.

The teachers completed approximately 1800 minutes of instruction over a semester. The mode of instruction was a) four 3-hour face-to-face class meetings held in the media center of the participating elementary school and b) online videos, assignments, etc. Face-to-face meetings generally focused on (a) what is argumentation, (b) how to implement argumentation, and (c) how to use collective argumentation to learn how to code within the context of mathematics and science content learning. Online assignments generally focused on learning coding content and educational robotics. Course activities were designed to (a) enhance teacher knowledge of argumentation and its application within the context of mathematics and science learning, (b) increase the teachers' ability to code robots, (c) develop the teachers' capacity to use collective argumentation in coding activities that were consistent with grade-appropriate mathematics and science content, and (d) to develop CALC-based mathematics and science lessons that could be applied in the teacher's elementary classroom.

Materials and Methods

This project has IRB approval for all phases of the study; all human subject regulations specified by our home university were followed.

Our research team was divided into two groups, the Instructional Group, and the Data Analysis Group. The Instructional group consisted of three faculty members who focused on the design and implementation of the CALC course. The Data Analysis Group consisted of three faculty members and five graduate students who observed how the instructors taught the course and how the teachers engaged the course material.

After the participating teachers completed the CALC course, they implemented the CALC approach to coding in their classroom. The research team served as instructional coaches with three team members assigned to each teacher. An instructional coach team reviewed the lesson plan the participating teacher was to implement and then observed how the elementary school students reacted to that plan. These observations included video recordings of the students learning how to code and the teacher working with those students. In each classroom, a group of students was followed throughout the implementation phase of this project.

Not all of the original 14 teachers implemented the CALC approach since some were reassigned to grade levels that were not part of this project. The implement the CALC approach took place three times during the fall portion of the 2018-19 school year. For all participating teachers, implementation began before the 7^{th} week of the school year, the 17^{th} week and the 23rd week (the end of the fall semester). At the end of each implementation event, the instructional coaching team met with the teacher and reviewed a video of the students working on a coding assignment. These meetings were audio recorded, transcribed and analyzed for changes in the use of the CALC approach. Analysis of these recordings are ongoing at the time of this paper (i.e., the analysis is in progress); complete analysis should be available at the conference presentation. All collect video data were analyzed by tracing teacher talk and the identification of themes, by identifying changes in coding structures and content and by detecting changes in the coding process.

At the beginning and the end of the CALC course, each teacher was interviewed. The semi-structured interview script is provided at the end of this paper. The interviews were designed to reveal the teachers' belief in coding as a subject to be taught in the elementary school curriculum and their belief in the CALC approach. The post-interview included questions designed to assess each teacher's content knowledge of coding.

During the CALC course, the teachers completed assignments related to building code to accomplish specific tasks. These online generated artifacts were analyzed to assess the teachers' content knowledge of coding and how they intended to integrate coding with other subjects such as mathematics. These artifacts, final exam and post-interview questions were reviewed to determine how efficient the teachers developed code where this was measured as

- Recognizing the importance of coding efficiency,
- Recommending specific coding strategies that increase efficiency,
- Using (demonstrating) specific coding strategies that increase efficiency, and
- Incorrect understanding, recommendation, or use of coding strategies.

The analysis also assessed the coding structures defined as

- Sequential control structure,
- Repetition control structure, and
- Selection control structure.

Each of these structures was quantified as the teacher

- Recognizes the structure,
- Recommends specific coding strategies that related that structure,

- Uses specific coding strategies that relate to that structure, and
- Incorrectly understands, recommends, or uses of these coding strategies.

Data Analysis

Survey items with Likert scale scores were analyzed using repeated measurement ANOVAs. Survey responses from teachers in non-partnering school districts were considered control responses. Open-ended survey responses were analyzed for themes. Both pre- and post-class teacher interviews were transcribed and then analyzed for reoccurring themes. Changes in themes were noted. The post-interview was analyzed to reveal teacher knowledge of coding structure.

Artifacts generated as part of course assignments were analyzed using rubrics designed to assess coding content. These artifacts were also analyzed for reoccurring themes.

Video recordings of the teachers discussing how their elementary school students completed a coding assignment were transcribed and analyzed for themes. Particular interest was given to the teacher's use of the CALC approach and how that use progressed during the 3 months that elementary school classroom observations were conducted.

Results

Findings at the time of this paper were preliminary. These findings have provided evidence of areas of success and failure. These preliminary results are presented in the following paragraphs.

When compared to the responses of teachers in non-partnering school districts, the pre-survey responses indicated no significant differences in the participating teachers' belief about the teaching of coding. For those who had 5 or more years of experience teaching, the partnering school district teachers had a stronger belief ($p=0.35$) in the use of the CALC approach in the learning of mathematics than teachers in the other non-partnering school districts. A similar difference ($p<.01$) was found for the "Ease of Using" argumentation to learn mathematics and science, but no difference in the "Ease of Using" argumentation for coding was found.

The participating teachers were asked to complete this same survey at the end of the CALC course, and the responses were completed to those provided at the beginning of the course. Overall, the pre-course responses and post-course responses suggest no significant differences in teacher attitudes about coding, except in one area. For teachers who had no or little previous experience with coding, a statistical difference was found related to the teachers' perception of Ease of Use of the CALC approach compared to those who had completed a professional workshop focused on educational robots.

Overall, the teachers recognized sequence, repetition, and selection control structures, and used related coding strategies although various forms/levels of coding knowledge were observed among participating teachers. Teachers who had little to no previous experience with coding defined "better" code as a structure that include more aesthetic visuals and sound but as the course progressed their work indicated that coding efficiency was related to fewer coding blocks. Teachers who entered the course with some coding background developed coding structures that included conditional and repeated structures as a means to improve coding efficiency. The teachers' ability to recognize or make a recommendation related to selection control was usually associated and rationalized using a visual output. Incorrect understanding of selection control and repetition control was observed at the mid-point of the course by almost all of the teachers who entered the course with no coding knowledge. Toward the end of the course, all but two teachers continued to have this misunderstanding. These two teachers requested continued help from the instructors during the first months of 2019. This help is being provided at the time of this paper.

After completing the CALC course, a subset of the teachers implemented CALC in their classroom. The classroom implementation began at the first of the school year, and the first session for all of the participating teachers consistently involved developing code to move a robot a given distance. The elementary school students who engaged in this activity consistently used trial-and-error to develop their code, although each teacher developed a lesson plan involving the CALC approach. For most of these students, this was their first time attempting to code a robot, and for some understanding, the mechanics of the robot was challenging. Through our review of the video recordings, we conclude the students tended to use trial-and-error as a means to learn robot mechanics and had fewer engagements focused on the development of code. The following provides an example conversation between students.

The first lesson plan presented was to introduce the students to velocity and the relationship of time and distance. The task was "*student will code a robot to move at a given speed and to move a given distance. The student will adjust the time the robot moves and related distance with time for different speeds. Students will be encouraged to determine and write an equation to represent the thinking behind their reasoning for coding the robot*". A group of 4th graders developed a code to move the robot forward for x seconds and coded the motor speed to 2, 4, and 6 (codes that relate to the speed that the motor drives the robot wheels). The students spent much of the time getting familiar with the robot and began to change the motor speed code to observe changes in the robot action. Next, the students were to use the same motor code and change the length of time the motor was on. After the robot moved, the students were to measure distance. General discussions revolved around why the robot move in a given manner particularly if it did not move in a straight line.

The teacher was interviewed after this session and discuss how the students engaged in a discussion to learn how to code.
What did you hope to accomplish with this instructional plan?
Teacher (direct quote): *I was trying to help them make note of what they were discovering as they were coding and how to make logical choices when changing their code. For this group, they tried to engage in doubling concept where if they double the delay [length the time the motor is one] then the distance traveled is doubled. But most of the students could not jump there but hopefully, they will after some more lessons. My plan was for them to look at what was happening and what did we change in the code and how could I use that result to make the code. They should take the time to*

analyze what did not work and to use what went wrong to change the code and make it more efficient.

The students were engaged in a conversation which I like, and how they discussed the [necessary] *to decrease the time to change the direction. But when they started to discuss decimals that's when the conversation went in the wrong direction. I think in the group, they made some statements of why something worked and why [something did not work]. They did have a reason for changing their code, but they did not necessarily understand why the change* [resulted] *in the robot motion. I wanted them to understand that based on what they see, they can use that to make a new decision on what changes need to be made. I wanted them to have that knowledge so when we move to a more advanced task. That was my main goal. If they use trial-and-error to get it to work, they think oh good we got it to work, but they have not constructed the knowledge needed for the next step. I think they need the analysis piece missing, that analysis piece is critical. That is something they need to do in every subject area. I think they were using trial-and-error and move more toward that as they had trouble with coding.*

The conversation continued to focus on the next lesson plan that implemented the CALC approach. The teacher asked for advice on how to present the CALC approach. The teacher wondered if she should present a claim on the board or have the students write down their claim on a sheet of paper.

The next lesson plan was to introduce the students to decimal placement and coding. The task was "*students will code a robot to move forward for set distances (marked off by painter's tape). The students will use learning from coding shorter distances to mathematically reason coding for longer distances. Students will be encouraged to determine and write a mathematical equation to represent the thinking behind their reasoning and determine hat variables might cause differences.*" The research team observed the conversations of the same group of 4th graders mentioned above. They developed a code to move the robot forward for 4 seconds but the robot undershot the desired distance. The students used data from the previous task to have data related to how long the motor was on and distance traveled. The following are direct quotes from the students as they discussed how to code the robot.

Student 1. *Our goal right now is to move it 12 inches. Why don't we try 2.4 seconds* [timing of the motors].

Student 2. *Did you switch it* [the time the motors were one]. *Why is it six and not four [2.6 not 2.4]?*

Student 3. *That is the way it is to be coded.*

Student 1. *No, no, it was curving way too much that way.*

Student 2. *Just keep it 2.4 that the way we had it.*

A 4th student used collective argumentation to reason out how to code the robot.

Student 4. *Here is our claim and we have to see if we are writing it as true or not and it turns out that it is not. It says* [previous data] *1.5 seconds is 6 inches and we at first think 2.4 would get us to 12 inches. But that claim is not true because it would have, cause you double it by 6. If it went 6 inches, 12 inches, you would double 1.5 to 3 seconds. So it would actually be 3 seconds, not 2.4 seconds.*

The teacher conducted a debriefing of the students and wrote the following for one of the student groups. The claim was "0.8 doubled is 1.6, so our delay for 12 inches should be 1.6 seconds. Data is 0.8 equals 6 inches. The warrant is 12 inches is doubled so the code should double the motor delay.

The teacher was interviewed after this session and discuss the CALC approach to learning how to code. The following are the teacher's responses to interview questions.

Interviewer: How did you come up with that instructional plan?

Teacher: *Well, I knew based on what they had done this idea of an understanding of decimals and the value of those previously, and which one's greater and which one's less, was a gap that they hadn't learned yet. And so I knew ... and again, that was one of those things we couldn't necessarily fully address in what we were doing previously, but since this was a problem they had to begin with, I really wanted it to be something that they then were able to explore through robotics. So that's kind of how I ended up with the whole fractions and decimals and fraction of a whole kind of situation. I don't know, I just really wanted it to be something that then led into some other thing that I knew they were gonna be studying or was already a question that they had, so they didn't just leave it hanging. And I thought they had some interesting questions that came up because of it, that I also think really helped them to understand conceptually what that really looks like.*

Interviewer: Did you envision the learning happening through the process of the students coding, or through the visualization of that physical robot?

Teacher: *Because I think that the coding alone is something that they have to do, some of that mathematical ... whether it's repetition or multiplying something, if it's point three, then how many times do I have to do that, those kinds of things. So to me, it went both ways. I don't think that I learned more towards one or the other, but I really saw all of that working together. I don't know if that makes sense or not.*

Interviewer: Can you talk about how the argumentation piece works into maybe that more challenging environment? Does it benefit argumentation? Is it more difficult to implement?

Teacher: *I think these kids, they like to try to argue their point. Even to the point that it's wrong but they still want to argue their point. Oh, they're shocked when it's wrong. But I think what I love about it is then it allows for them to hear the opinion of somebody else or to be questioned by somebody else, and that was the whole reason I pushed for advanced content was so that we could have it with kids that think at their level and could challenge their thinking. Because that doesn't happen a lot. And I think with argumentation, it's a great way for kids who need that back and forth with somebody to be able to do that. Again, with somebody who can go, "That's not right." Not because they're just arguing, but because they actually know. And in some cases, most kids would just be sitting there and be like, "Oh, okay, we'll just do that." But I love that they have that back and forth with each other.*

I guess what I keep going back to is what I think about kids in general, no matter where they are and where they live and what backgrounds they come from, they are going to be put in a world in which they have to be able to have these skills. Not only to try to prove their point but to listen to the points of others. So I think that's one of the most beneficial things about this is it allows for that. So no matter what job they're

> *doing, or if it's in their relationships with their friends, and we know that that's a huge problem in our world today. So I just think if we can develop that in them through whatever it is, to me, it makes total sense to do it.*

Concluding Statement

Overall, the implementation of the CALC approach demonstrates the growth of the teachers in their ability to teach coding as a reasoning process and as a mean to integrate it into everyday classroom activities. The second cohort of teachers are learning the CALC approach as this paper is being written and they will implement the process in the fall of 2019.

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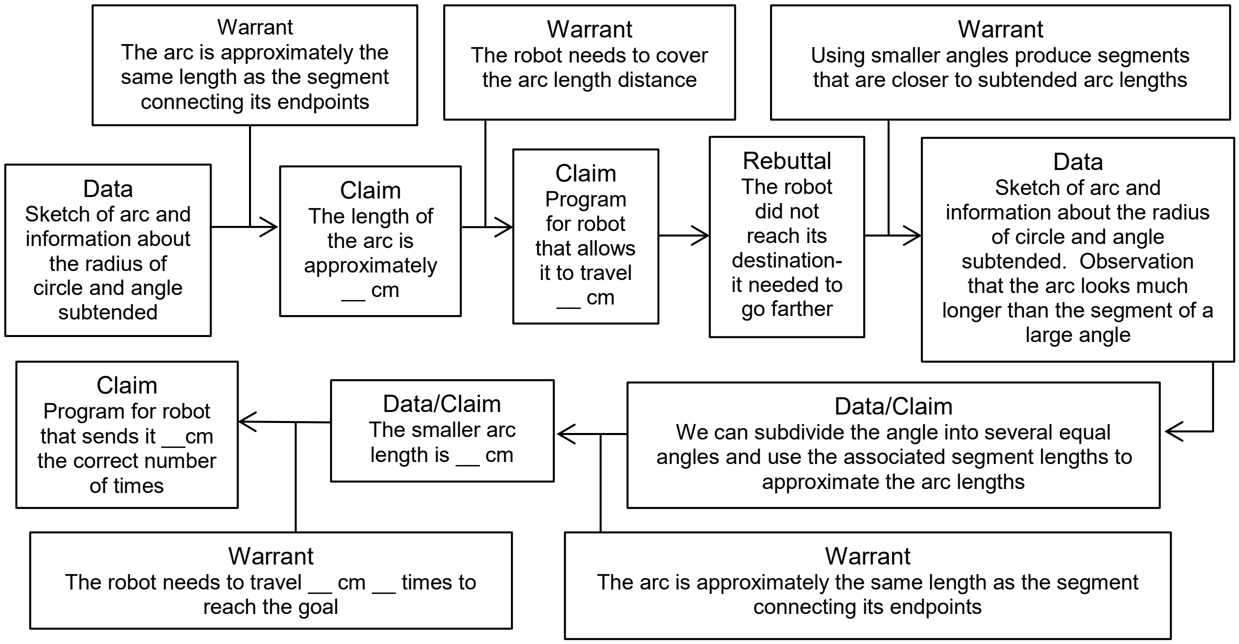

Figure 1. A teacher and students discuss measuring the length of an arc and how to program a robot to transverse an arc.