Analyzing Teacher Supports for Collective Argumentation in Integrative STEM Classrooms (RTP)

Abstract

The Next Generation Science Standards [1] recognized evidence-based argumentation as one of the essential skills for students to develop throughout their science and engineering education. Argumentation focuses students on the need for quality evidence, which helps to develop their deep understanding of content [2]. Argumentation has been studied extensively, both in mathematics and science education but also to some extent in engineering education (see for example [3], [4], [5], [6]). After a thorough search of the literature, we found few studies that have considered how teachers support collective argumentation during engineering learning activities.

The purpose of this program of research was to support teachers in viewing argumentation as an important way to promote critical thinking and to provide teachers with tools to implement argumentation in their lessons integrating coding into science, technology, engineering, and mathematics (which we refer to as integrative STEM). We applied a framework developed for secondary mathematics [7] to understand how teachers support collective argumentation in integrative STEM lessons. This framework used Toulmin's [8] conceptualization of argumentation, which includes three core components of arguments: a *claim* (or hypothesis) that is based on *data* (or evidence) accompanied by a *warrant* (or reasoning) that relates the data to the claim [9], [8]. To adapt the framework, video data were coded using previously established methods for analyzing argumentation [7].

In this paper, we consider how the framework can be applied to an elementary school teacher's classroom interactions and present examples of how the teacher implements various questioning strategies to facilitate more productive argumentation and deeper student engagement. We aim to understand the nature of the teacher's support for argumentation—contributions and actions from the teacher that prompt or respond to parts of arguments. In particular, we look at examples of how the teacher supports students to move beyond unstructured tinkering (e.g., trial-and-error) to think logically about coding and develop reasoning for the choices that they make in programming. We also look at the components of arguments that students provide, with and without teacher support. Through the use of the framework, we are able to articulate important aspects of collective argumentation that would otherwise be in the background. The framework gives both eyes to see and language to describe how teachers support collective argumentation in integrative STEM classrooms.

Introduction

The Next Generation Science Standards [1] (NGSS) included evidence-based argumentation as one of its core practices in science and engineering education that should be developed throughout primary and secondary school education. The National Research Council (NRC) wrote that "In engineering, reasoning and argument are essential to finding the best possible solution to a problem…. [S]tudents should argue for the explanations they construct, defend their interpretations of the associated data, and advocate for the designs they propose" [10, pp. 72-73].

The NGSS specifically included engaging in argument and constructing explanations supported by evidence in its middle and high school engineering design standards [1]. Argumentation focuses students on the need for quality evidence, and the process helps students to build connections between ideas and improve their understanding of concepts, developing a deeper understanding of content [2].

Argumentation has been studied extensively in both mathematics and science education (see, for example, [3], [4], [5]), where it has often connected with mathematical proof and evidence-based reasoning in science, but it has also grown into a research discipline of its own. Research into argumentation in engineering education, however, has been limited, and most of the research was focused on the argumentation of students rather than on the role of teachers [6]. We also conducted a thorough search of the literature, but we found few studies that consider how teachers can support argumentation in engineering learning activities. The research that we did find was focused on curricular activities developed by teachers rather than on their classroom practices (see for example, [11], [12]).

Coding with unplanned steps or through tinkering with existing code is common to both formal and informal programs on computer science education. These approaches emphasize unstructured processes like trial-and-error or tinkering. Some studies in the literature provide evidence that trial-and-error exploration has a positive impact on learning when that exploration is provided with facilitated support that keeps the learner from becoming frustrated or getting the feeling of being unable to do the task [13], [14], [15], [16]. Instead, our study uses a structured approach to coding, by which we mean coding through a more planned approach in which students support their decision making through argumentation.

Our program of research helped teachers to see argumentation as a tool to promote critical thinking in young people across disciplines and to provide teachers with ideas about how to implement argumentation in their teaching of science, technology, engineering, and mathematics, as well as lessons integrating coding into the other fields (which we refer to as integrative STEM). In this paper, we investigate how the existing Teacher Support for Collective Argumentation (TSCA) framework [7], which was developed for mathematics classrooms, applies to this interdisciplinary STEM context. We present examples of how an elementary school teacher implements various questioning strategies to facilitate more productive argumentation and deeper student engagement. The intent for using the TSCA framework is to understand the nature of teachers' support for argumentation and how the teacher supports students to move beyond trial-and-error to think logically about coding and develop reasoning for the choices that they make in programming. The research question we seek to answer is: How does the TSCA framework [7] apply in an integrative STEM context and assist in understanding how a teacher engages students in collective argumentation to support a structured approach to coding? This paper is an exploratory study considering the merit of adapting the TSCA for an interdisciplinary context.

Collective Argumentation

We define collective argumentation as teachers and students working together to establish a claim and provide evidence to support it (see [9]). We consider the term broadly to include any situation where students or teachers make a claim and multiple people provide support for it. Once a collective argument is identified, we can apply the TSCA framework [7] (see Table 1) to understand how teachers support the collective argumentation in integrative STEM contexts. Although this framework was designed for mathematics, our research was focused on whether the TSCA framework could be applied to the interdisciplinary STEM context with the understanding that references in the framework to mathematics (such as "mathematical fact" or "mathematical exploration") would be understood to be the equivalent in the disciplinary context of a field in STEM, whenever it made sense to do so. For example, this would mean that our understanding of "Requesting an idea" was adapted from the original definition [7, p. 418] to one which considers when a teacher "Asks students to compare, coordinate, or generate" ideas in a STEM context. For this reason, we present the framework in its original mathematical context with the understanding that the ideas were considered in the context of another discipline, when it made sense to do so. The TSCA framework was built on Toulmin's conceptualization of argumentation [8] and always includes three core components of arguments: a *claim* (or hypothesis) that is based on *data* (or evidence) and accompanied by a *warrant* (or reasoning) relating the data to the claim, which may be explicitly stated or implicit [9], [8]. Other components of arguments can be found in Table 1. The framework categorizes teacher support of collective argumentation into three categories: (a) direct *contributions* of argument components (such as claim, data, or warrant), (b) *questions* that elicit student contributions, and (c) *other supportive actions* that respond to student contributions. Table 1 shows the original framework in its entirety.

Table 1 The Teacher Support for Collective Argumentation (TSCA) Framework for Mathematics (Reprinted by permission from Springer: Springer Nature, Educational Studies in Mathematics, "Teacher support for collective argumentation: A framework for examining how teachers support students' engagement in mathematical activities", A. Conner, L. M. Singletary, R. C. Smith, P. A. Wagner R. T. Francisco, Springer Science+Business Media Dordrecht 2014)

Direct Contributions		Questions		Other Supportive Actions	
Claims	Statements whose validity is being established	*Requesting a factual answer*	Asks students to provide a mathematical fact	*Directing*	Actions that serve to direct the students' attention and/or the argument
Data	Statements provided as support for claims	*Requesting a method*	Asks students to demonstrate or describe how they did or would do something	*Promoting*	Actions that serve to promote mathematical exploration
Warrants	Statements that connect data with claims	*Requesting an idea*	Asks students to compare, coordinate, or generate mathematical ideas	*Evaluating*	Actions that center on the correctness of the mathematics
Rebuttals	Statements describing circumstances under which the warrants would not be valid	*Requesting elaboration*	Asks students to elaborate on some idea, statement, or diagram	*Informing*	Actions that provide information for the argument
Qualifiers	Statements describing the certainty with which a claim is made	*Requesting evaluation*	Asks students to evaluate a mathematical idea	*Repeating*	Actions that repeat what has been or is being stated
Backings	Usually unstated, dealing with the field in which the argument occur				

Methods

The mathematics, science, and engineering faculty at a university in the southeastern part of the United States developed a professional development experience for elementary level teachers. The semester-long hybrid course used face-to-face in-class meetings and weekly online learning activities. Teachers learned about how to integrate coding into their lessons in a way that emphasized a structured approach to coding. The teachers often chose to develop lessons that integrated coding into their STEM lessons, but some teachers also decided to integrate coding into their literature or social studies lessons. Teachers chose whatever system of coding that they wanted (including Ozobots/Ozoblockly [17] or Scratch).

After the professional development course, the research team followed four teachers into their classrooms to investigate how they implemented such lessons. The team observed and videorecorded approximately three lessons from each teacher. We interviewed teachers before and after each lesson to discuss the choices that they made in implementing their lessons. We examined the video recordings of the classes to identify episodes of argumentation, which we then then transcribed, noting important embodied gestures and movements. Two members of the research group analyzed each video and each transcript, and they discussed it until a consensus was reached. We analyzed transcripts by creating extended Toulmin diagrams [7]. In these diagrams, colors and line styles indicate who contributed that addition to the argument. Notice that teacher contributions are outlined in solid red, student contributions are outlined in dashed blue, and contributions that come from both teacher and students together are outlined in dash-dot purple (none of which are in the figures). Initial data that comes from before to the start of the argument is outlined in solid green. Rectangles represent argument components while ovals represent supports for argumentation. An example of a relevant extended Toulmin diagram can be found in Figure 1, along with the transcript from which it was developed.

In the creation of these extended Toulmin diagrams, we identified components of arguments (data, claims, and warrants), teacher questions, and teachers' other supportive actions. These components are labeled in the diagram, and their position with respect to the arrow also indicates the argument component. Single arguments are often combined into chains of reasoning where claims from one argument form a component of another argument (like the data/claim in figure 1). Diagrams were also created by two members of the research group and discussed until a consensus was reached. Building from the extended Toulmin diagrams, we used the TSCA framework [7] to code the teachers' support for argumentation into specific categories of types of questions and types of other supportive actions. Each teacher question and supportive action was coded individually by members of the research group; discrepancies were discussed collectively until consensus was reached by the group.

Katy (note that all names have been changed to preserve anonymity), a fifth-grade elementary school teacher, participated in the initial professional development course. She taught all subjects to twenty-one students. She integrated the coding of Ozobots into her mathematics and social studies activities. Ozobots are small, educational robots that use a block-based programming language Ozoblockly [17]. Over the course of four lessons, she worked with students on various coding tasks, including coding the Ozobot to follow a path specified by the teacher and flashing certain colored lights at different points of the path. Katy's class was selected for analysis for this paper because the primary disciplinary focus of the arguments in her lessons was on integrative coding and the arguments from her class primarily featured her and the students, as opposed to including many contributions from the research team (e.g., to help with overcoming a coding or argumentation challenge).

Results

A common issue in coding lessons is the over-reliance of students on unsystematic, trial-and-error approaches, which is commonly used by novice programmers [16]. The NRC recommends that engineering teachers emphasize decision-making based on evidence rather than trial-and-error [10]. We were especially interested in breaking down specific episodes of argumentation in which students encountered issues in their code. In Katy's arguments, we observed how she supported students' collective argumentation towards correcting the programming code using structured coding as opposed to unstructured approaches. In this paper we consider two episodes of argumentation related to code improvement.

In her third lesson on coding, Katy planned to integrate coding Ozobots into her social studies lesson. Her lesson focused on studying the history of immigration to the United States at Ellis Island and the drastically different experiences of different kinds of passengers. For example, immigrants who arrived in different travel classes or had different health or language challenges had different experiences at Ellis Island. Katy presented the students with a large map (shown within Figure 1) and gave each group of students a profile of a family arriving at Ellis Island. She asked students to program a path for their Ozobots on the map to model the experience of that family arriving at Ellis Island. Different aspects of the family profile corresponded to unique experiences at different stations along the path through Ellis Island, including the nurse's station, baggage room, currency exchange, and kissing post. Aspects of their profile impacted the speed and the delays that each family faced there. Katy's learning goal was for students to understand how to use the Ozobots to model the immigrant experience at Ellis Island and how a passenger's identity impacted their experience there. In this episode of argumentation, one student stopped Katy to ask questions about the specific path her Ozobot needed to travel. The conversation took place in front of the map of Ellis Island (shown within Figure 1). Katy proceeded to engage the student in constructing an argument for how many "steps" the Ozobot should move forward, through questions from the "Requesting an idea" category as well as other supportive actions from the informing and promoting categories (see Figure 1 and transcript). Katy requested ideas and encouraged reasoning towards an idea that could provide a way to improve the code and get the Ozobot to navigate efficiently through the map. One of the warrants was left implicit.

> Katy's Small Group Discussion About Choosing the Most Efficient Path for an Ozobot to Travel Though Ellis Island (see Figure 1).
> (0:21:14.6) Katy: So, you went there, there, you kind of hit the corner but now you don't even have to worry about it, around, so now you have passport and border.
> (0:21:22.1) S1: Mine doesn't work.
> (0:21:23.7) Katy: Which… Hold on just a second S1… which way do you think is most efficient? Because you're at currency, but you've got to hit those two. Which way is the most efficient?
> (0:21:34.2) S2: I was gonna go like that, like that, and then like that (points with fingers).

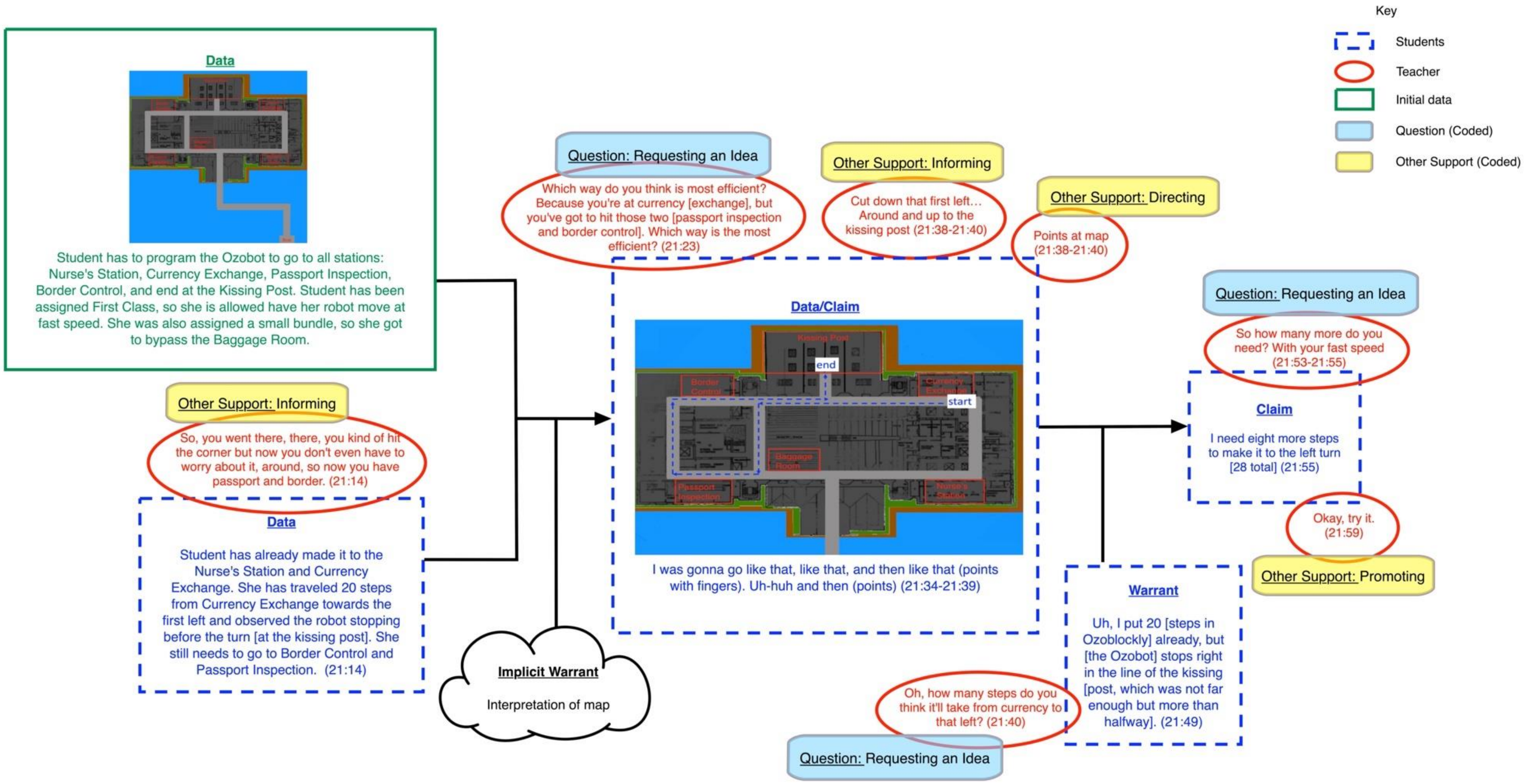

Figure 1 The diagram of the collective argument from Katy's small group discussion about how to choose the most efficient path for an Ozobot through Ellis Island (see transcript). The diagram indicates the specific roles of the teacher and student contributions to the argument.

(0:21:38.2) Katy: Cut down that first left?
(0:21:39.1) S2: Uh-huh and then (points).
(0:21:40.9) Katy: Around and up to the kissing post. Ok. Oh, how many steps do you think it'll take from currency to that left?
(0:21:49.8) S2: Uh, I put 20 already, but it stops right in the line of the kissing booth.
(0:21:53.8) Katy: So how many more do you need?
(0:21:54.8) S2: Like...
(0:21:55.4) Katy: With your fast speed?
(0:21:57.0) S2: Like, 8. 8.
(0:21:59.5) Katy: Ok, try it.

In her fourth coding lesson, also intended to integrate coding and social studies, Katy's class was studying a World War II battle and how the soldiers communicated through code. The students were asked to program their Ozobot to model how a group of American soldiers travelled around the battlefield, from the landing site to a tank to near a German soldier to a cliff and ending at a flag. At each of these stations, the soldiers sent a coded message to their commander. In the classroom, the Ozobot modeled how the troops traversed the battlefield, which was represented by images on the floor of the classroom. For each of the codes, the Ozobot was supposed to flash a specific sequence of lights. In this episode of argumentation, Katy interacted with a group of students who were able to program the Ozobot to reach the various locations on the battlefield, but they struggled to make the Ozobot flash the appropriate sequence of colors. The Ozobot kept flashing a red light rather than the appropriate sequence of colors. When Katy approached the group, she used various types of questions to support students' collective argumentation: "Requesting a factual answer," "Requesting elaboration," and "Requesting an idea" (see Figure 2). Notably, in this case, as well as the previous case, Katy ended the interaction with her students by using a support from the "Promoting" category, encouraging them to continue working towards the solution and developing the ideas that they discussed in the arguments.

Katy Troubleshooting the Ozobot's Flashing Lights in a Small Group (see Figure 2).
(0:19:13.9) S3: Ours is just, uh, getting red. We put…
(0:19:17.0) Katy: So, let's see
(0:19:17.3) S4: Yea, red flashing... other colors
(0:19:18.2) S3: ...red, green, red.
(0:19:19.2) Katy: We have move forward very very fast. Did that get you to the tank?
(0:19:23.0) S3: Yes
(0:19:24.2) Katy: It did?
(0:19:24.8) S3: And it went like it went right on the side of the soldier.
(0:19:29.9) Katy: The soldier?
(0:19:31.1) S4: Right where it passes the...
(0:19:32.1) Katy: Oh, after this second movement? What's next? Ok, German soldier, yea. So, you have the colors. What's your problem?
(0:19:41.1) S3: It won't stop flashing red. Yea...
(0:19:43.3) Katy: Why do you think that's the case?
(0:19:45.7) S4: I don't know.
(0:19:46.3) S3: Because we need it to go like every single color, but at first it goes red, green, red. But then it just goes red, red, red, red, red, red,...

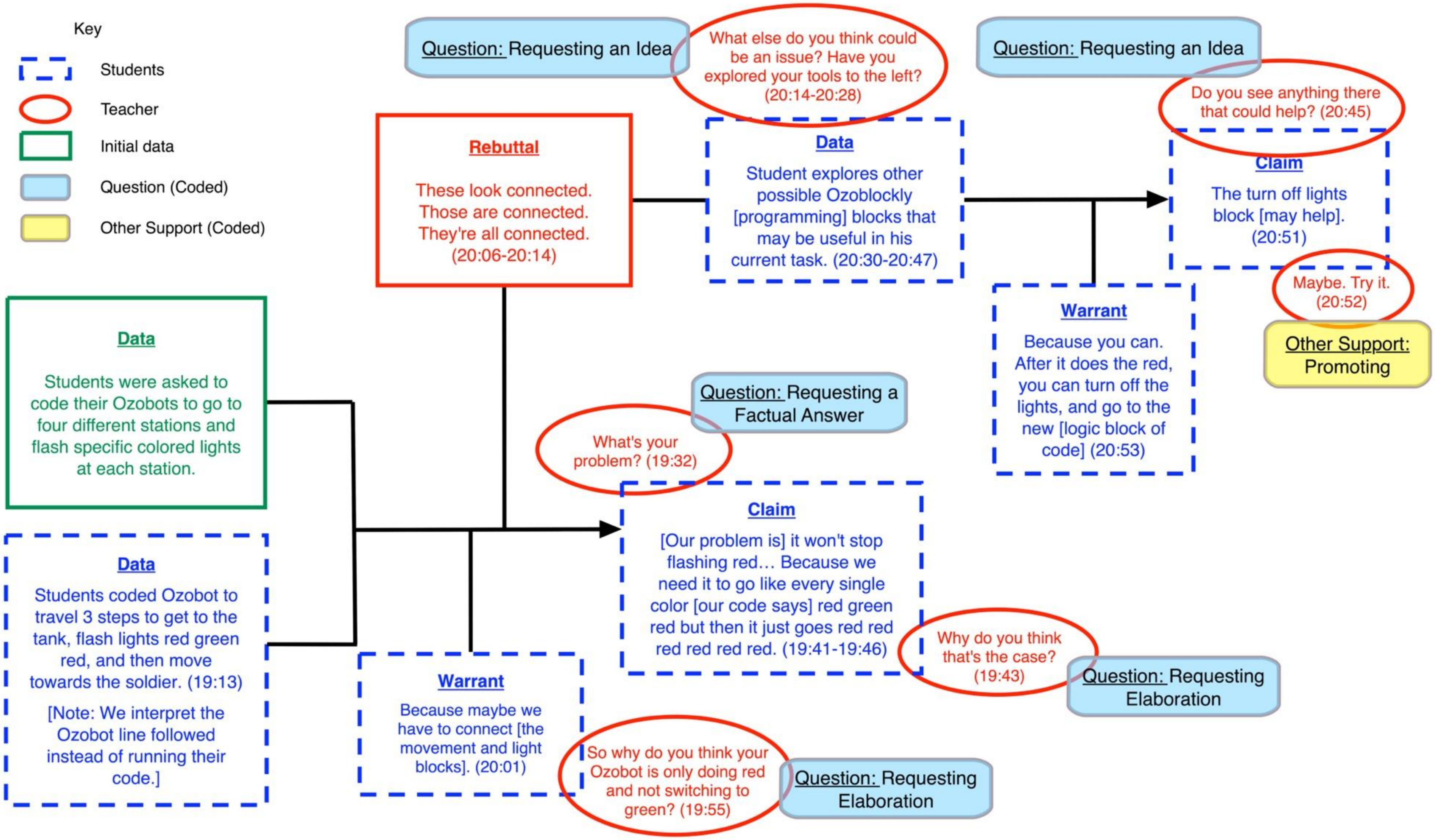

Figure 2 The diagram of the argument from Katy's small group discussion troubleshooting the Ozobot's flashing lights (see transcript).

(0:19:55.8) Katy: So why do you think your Ozobot is only doing red and not switching to green?
(0:20:01.2) S3: Because maybe we have to connect them. We have to connect the ... (points to screen).
(0:20:06.1) Katy: These look connected. Those are connected.
(0:20:09.0) S3: No, I'm talking about these with these, and those with those (points at screen) to that.
(0:20:14.8) Katy: They're all connected. What else do you think could be an issue?
(0:20:24.0) S3: Umm....
(0:20:28.4) Katy: Have you explored your tools to the left?
(0:20:30.6) S3: Uh-huh. We've only been using… [Student,] come here, we've been using these...
(0:20:36.6) Katy: [Student 4]
(0:20:39.3) S3: And like wait a minute (looks at board).
(0:20:45.5) Katy: Mmm. Do you see anything there that could help?
(0:20:47.6) S4: Uh-uh (negative)
(0:20:49.7) S3: Yes.
(0:20:50.5) Katy: What?
(0:20:51.3) S3: The turn off lights.
(0:20:52.1) Katy: Maybe. Try it.
(0:20:53.4) S3: You can, because you can. After it does the red, you can turn off the lights, and go to the new one.
(0:21:00.0) Katy: Yea, but let's work up here first because this is first. So, we have move forward, red, and do you want the red to continue or do you want it to turn off?
(0:21:09.3) S3: Turn off.
(0:21:09.9) Katy: Ok so how do you tell the red to turn off?
(0:21:12.6) S4: Turn light off.
(0:21:14.0) Katy: You might need to get a new one. Or duplicate. I didn't know you could do that.

Conclusion and Implications

In this paper, we sought to answer the following question: How does the TSCA framework [7] assist in understanding how a teacher engages students in collective argumentation to support a structured approach to coding? By examining episodes of Katy's lessons with the TSCA framework, we could see how the collective arguments were laid out, and we identified how she supported argumentation with different types of questions and other supportive actions. Her questions prompted students to provide ideas and elaborate on them. Her other supportive actions promoted their continuing to explore the situation using coding. The framework helps us to identify how Katy assisted her students in structured coding by facilitating collective argumentation based on evidence and reasoning. Students were not left to informal methods, like trial-and-error.

This is one of the first applications of the TSCA framework outside of mathematics education. Our research is in progress as we try to update and extend the TSCA framework in engineering and coding contexts. By understanding how teachers engage students in collective argumentation in these contexts, we can obtain insights into productive ways to support students in coding. These insights can be used in professional development and teacher education settings to enhance teachers' knowledge of pedagogical strategies in the teaching and learning of coding in interdisciplinary settings. Additionally, these strategies can be extended to the tertiary level as we engage in engineering and coding instruction.

References

[1] NGSS Lead States. *Next Generation Science Standards: For States, by States*. Washington, DC, USA: National Academies Press, 2013. [Online]. Available: https://doi.org/10.17226/18290. (Accessed Nov. 12, 2021).

[2] E. M. Nussbaum, "Collaborative discourse, argumentation, and learning: Preface and literature review," *Contemporary Educational Psychology*, vol. 33, no. 3., July 2008. [Online]. Available: https://doi.org/10.1016/j.cedpsych.2008.06.001. (Accessed Nov. 12, 2021).

[3] G. Krummheur, "Argumentation and participation in the primary mathematics classroom: Two episodes and related theoretical abductions," *The Journal of Mathematical Behavior*, vol. 26, no. 1, 2007. [Online]. Available: https://doi.org/10.1016/j.jmathb.2007.02.001. (Accessed Nov. 12, 2021).

[4] M. Inglis, J. P. Mejia-Ramos, and A. Simpson. "Modelling mathematical argumentation: The importance of qualification," *Educational Studies in Mathematics*, vol. 66. [Online]. Available: https://doi.org/10.1007/s10649-006-9059-8. (Accessed Nov. 12, 2021).

[5] R. Driver, P. Newton, and J. Osborne. "Establishing the norms of scientific argumentation in classrooms," *Science Education*, vol. 84, no. 3, May 2000. Available: https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A. (Accessed Nov. 12, 2021).

[6] A. Wilson-Lopez, A. R. Strong, C. M. Hartman, J. Garlick, K. H. Washburn, A. Minichiello, S. Weingart, and J. Acosta-Feliz. "A systematic review of argumentation related to the engineering-designed world," *Journal of Engineering Education*, vol. 109, no. 2, Apr. 2020. [Online]. Available: https://doi.org/10.1002/jee.20318. (Accessed Nov. 12, 2021).

[7] A. Conner, L. M. Singletary, R. C. Smith, P. A. Wagner, and R. T. Francisco. "Teacher support for collective argumentation: A framework for examining how teachers support students' engagement in mathematical activities," *Educational Studies in Mathematics,* vol. 86. [Online]. Available: https://doi.org/10.1007/s10649-014-9532-8. [Accessed Feb. 12, 2022].

[8] S. Toulmin, *The uses of argument*, 2nd ed. Cambridge, UK: Cambridge University Press, 2003.

[9] G. Krummheuer, "The ethnography of argumentation," in *The Emergence of Mathematical Meaning: Interaction in Classroom Cultures*, P. Cobb and H. Bauersfeld, Ed. New York, NY, USA: Routledge, 1995.

[10] National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core*. Washington, DC, USA: National Academies Press, 2012. [Online]. Available: https://doi.org/10.17226/13165. (Accessed Nov. 12, 2021).

[11] E. A. Siverling, T. J. Moore, E. Suazo-Flores, C. A. Mathis, and S. S. Guzey. "What initiates evidence-based reasoning?: Situations that prompt students to support their design ideas and decisions," *Journal of Engineering Education*, vol. 110, no. 2, Apr. 2021. [Online]. Available: https://doi.org/10.1002/jee.20384. (Accessed Nov. 12, 2021).

[12] D. H. Jonassen and Y. H. Cho. "Fostering Argumentation While Solving Engineering Ethics Problems," *Journal of Engineering Education*, vol. 100, no. 4, Oct. 2011. [Online]. Available: https://doi.org/10.1002/j.2168-9830.2011.tb00032.x. (Accessed Nov. 12, 2021).

[13] B. Bevan, J. P. Gutwill, M. Petrich, and K. Wilkinson. "Learning Through STEM-Rich Tinkering: Findings From a Jointly Negotiated Research Project Taken Up in Practice," *Science Education*, vol. 99, no. 1, Jan. 2015. [Online]. Available: https://doi.org/10.1002/sce.21151. (Accessed Apr. 1, 2022).

[14] L. C. Pagano, C. A. Haden, and D. H. Uttal. "Museum Program Design Supports Parent-Child Engineering Talk During Tinkering and Reminiscing," *Journal of Experimental Child Psychology*, vol. 200, Dec. 2020. [Online]. Available: https://doi.org/10.1016/j.jecp.2020.104944. (Accessed Apr. 1, 2022).

[15] A. Simpson, A. Burris, and A. Maltese. "Youth's Engagement as Scientists and Engineers in an Afterschool Making and Tinkering Program," *Research in Science Education*, vol. 50, no. 1, Feb. 2020. [Online]. Available: https://doi.org/10.1007/s11165-017-9678-3. (Accessed Apr. 1, 2022).

[16] M. Berland, T. Martin, T. Benton, C. Petrick Smith, and D. Davis. "Using learning analytics to understand the learning pathways of novice programmers," *Journal of the Learning Sciences* vol. 22, no. 4, 2013. [Online]. Available: https://doi.org/10.1080/10508406.2013.836655. (Accessed Feb. 12, 2022).

[17] Ozobot. "OzoBlockly." Ozobot.com. https://ozobot.com/create/ozoblockly. (Accessed Feb. 12, 2022).

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