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Serious and Playful Inquiry: Epistemological Aspects of Collaborative Creativity

Florence R. Sullivan
University of Massachusetts, Amherst, MA, USA // fsullivan@educ.umass.edu

ABSTRACT

This paper presents the results of a micro-genetic analysis of the development of a creative solution arrived at by students working collaboratively to solve a robotics problem in a sixth-grade science classroom. Results indicate that four aspects of the enacted curriculum proved important to developing the creative solution, including the following: an open-ended, goal-oriented task; teacher modeling of inquiry techniques; provision of tools and an environment that allowed students to move between dual modes of interaction (seriousness and play); and provision of tools and an environment that allowed students to jointly develop a shared understanding achieved through tool-mediated, communicative, and cognitive interaction. The findings suggest that play is an important mode of inquiry if creativity is the learning goal. Implications of this research for the design of learning spaces as well as directions for future collaborative creativity research are discussed.

Keywords

Creativity, Dialogism, Bricolage, Robotics, Collaborative problem-solving

The purpose of this paper is to further our understanding of collaborative creativity among middle-school students. National technology standards expressly discuss creativity as a desired learning outcome for K12 students (International Society of Technology in Education, 2007). This may be due to an envisioned need to address increasingly complex societal problems through innovation. Sonnenburg (2004) argues that collaborative teams will be an essential aspect of such creative work in the future. Collaborative creativity, then, is an important yet relatively new focus of research (Sawyer & DeZutter, 2009). As such, there is a limited amount of K12 educational research related to this topic. The research that does exist has shed light on two areas of collaborative creativity: group dynamics and local classroom practices.

Developing a shared understanding of a task through intersubjectivity is a key aspect of successful collaborative problem-solving (Roschelle & Teasley, 1995). However, it seems that for creative solutions, some level of disagreement or conflict regarding the task increases the groups' overall creativity (Chiu, 2008; Kurtzberg & Amabile, 2001), whereas personal or processual conflict will negatively affect the groups' creativity (Eteläpelto & Lahti, 2008). Vass, Littleton, Miell, and Jones (2008) found that for a collaborative creative-writing task, students' emotional reactions to the assignment also affect the quality of their creative work.

Researchers have identified local classroom practices that bear on collaborative creativity. These practices include language play, musing, singing, humor, acting out, and role-playing games (Fernández-Cárdenas, 2008; Vass, et al., 2008). These practices serve to open a space for all students to engage and offer ideas for consideration. Collaborative creativity also includes practices such as planning together, sharing opinions, building on and integrating one another's ideas, arguing for one's ideas, negotiation and coordination of viewpoints, and seeking agreement on points of discussion (Rojas-Drummond, Albarrán, & Littleton, 2008, p. 186).

This early research has begun to lay an empirical foundation for understanding phenomena involved in collaborative creativity. Yet, as Sonnenburg (2004) argues, we are still in need of a strong theoretical basis for understanding collaborative creativity, and as Sawyer and DeZutter (2009) point out, we know little about how creative ideas develop within a group. In this paper, I address both of these issues by examining the interactions of a small group of sixth graders solving a robotics problem. I analyze their interactions based on Bakhtin's (1981, 1986) theory of dialogism, providing a dialogic analysis of how a small group develops a creative solution to a technology problem.

Dialogism

Dialogism (Bakhtin, 1981) is a theory of communication that refers to the constant interplay of social forces on the meanings we make of the words we speak. In Bakhtin's formulation, the meanings of words are not fixed but are

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dependent on the socio-ideological position of the speaker of the words and the situation in which the words are spoken. Bakhtin (1986) theorizes that all communication is historically situated and responsive to the anticipated understanding and response of the addressee. In this way, each utterance is multi-voiced and temporally dynamic, containing the voices of previous speakers and shaped by the anticipated voice of future speakers.

Bakhtin (1981) argues that people develop their frameworks for knowledge by appropriating the discourses of others. These appropriated discourses constitute the lens through which experience is filtered. Bakhtin has identified two types of discourse: authoritative discourse and internally persuasive discourse. Authoritative discourses emanate from hierarchical sources, demand to be accepted as they are, and are not open to the perspective of the other. Sources of authoritative discourse may be religious, political, familial, or educational. Internally persuasive discourses, on the other hand, may be altered, extended, or framed in new contexts. These discourses can be creatively developed to take on new meanings.

Internally persuasive discourses are expressed not only through speech and writing, but also through material culture. As D'Andrade (1986) noted, "Material culture — tables, chairs, buildings, and cities — is the reification of human ideas in solid medium" (p. 22). Indeed, it may be argued that the mediating power of a material object is derived in part from the accumulation of knowledge of prior generations inherent in the design of the artifact itself (Cole & Engestrom, 1993). Similarly, designed environments also reify the ideas of the creators of these environments (Pea, 1993) and in so doing reflect the voice of the designer.

From a Bakhtinian perspective, knowledge construction is a creative process of assimilating and transforming internally persuasive discourses that surround one in a given culture. Creativity, from this perspective, develops through the active engagement with, and transformation of, internally persuasive discourses and is an act of learning. One would expect, then, that in a classroom, creative ideas emerge and new meanings are made through engagement with the internally persuasive discourses among students.

Dialogism thus suggests an analytic approach for studying collaborative creativity in the classroom: focus on the interaction of internally persuasive discourses in students' activities. In other words, analysis should focus on *how* students are making meaning based on their engagement with the classroom's material objects, the structured environment, and other people in the classroom. Based on this theoretical stance, two research questions are pursued in this study of collaborative creativity: What are the dialogic influences present in the classroom? How do these dialogic influences interact to aid in the development of the creative solution?

Methods

Design, participants, and data collection

This case study follows a focal group of students in a sixth-grade science classroom at a middle school in Holyoke, Massachusetts, as they solved a light-sensor-enabled robotics problem. Seventy-four percent of students in Holyoke Public Schools are Latino. The focal group consisted of three 12-year old Latina/o students, two girls and a boy. The teacher, Mr. Smith, was a 25-year old white male with three years of teaching experience. The focal group was video- and audio-taped over a 12-day period as they engaged in the curriculum. The curriculum for this study utilized modified lessons developed by Cooper (2004) and Bratzel (2007). The curriculum focused on computer science, physics (light and heat energy), and science literacy concepts. All of the whole-class, teacher-group, and community-group interactions were also video- and audio-taped. Researcher notes were taken each day in the class. At the end of each class session, my research assistant and I discussed our observations and I wrote a set of general notes based on this discussion. Two interviews were conducted with the teacher, one at the end of the first week of the implementation and one at the end of the unit. Pseudonyms are used throughout.

Data analysis

A modified form of interaction analysis (Jordan & Henderson, 1995) was used to analyze the videotaped data. Rough content logs of the data were recorded at the actual time of videotaping, and a finer grained log was created in subsequent viewings of the videotapes. The content logs and the researcher notes were consulted to identify episodes where a creative solution was found by the group. Of the six robotics challenges posed to the students, two of the challenges were solved by the students using a novel idea. I selected one of these episodes for further analysis based on the efficaciousness of the solution. The goal of this analysis is to understand how creative solutions are developed in groups. Therefore, it seems appropriate to select the strongest example of such a solution for analysis. Analysis related to the classroom environment was conducted using my notes and the interview I conducted with the teacher. The notes serve to develop a description of the classroom environment from which specific discourses can be discerned. Analysis proceeded from such description and was triangulated through the interview with the teacher.

In open-ended, collaborative approaches to robotics activity, students typically develop a troubleshooting cycle that consists of (1) writing and testing the program, (2) diagnosing problems with the program or structure of the device, (3) proposing and arguing for specific changes to the program/structure, (4) making changes to the program/structure, and (5) testing the device again. In order to systematically trace the development of the creative solution during the selected episode, I defined the troubleshooting cycle as the unit of analysis.

Analysis of the troubleshooting cycles proceeded in two steps. First, I applied the following procedure to each cycle: (1) identify the problem the students diagnosed, (2) determine the problem-solving ideas forwarded by each student, (3) identify the type of strategy the students were suggesting and/or the reasoning they were using to advance their respective ideas, (4) note the progression of the discourse as reflected by engagement with each other's ideas, and (5) note the appearance/re-appearance of specific ideas. Second, I determined the internally persuasive discourses students were engaging with during problem-solving. Strauss and Corbin (1990) note that one may create a set of analytical codes based on a theoretical rationale. I have done so in this analysis. Utilizing the theory of dialogism as discussed above, I identified the spoken and reified voices present in the classroom environment. I then used these codes to identify which voices were present during the problem-solving session. Then I determined the influence of these voices on student activity. I did this by focusing on how spoken ideas were taken up (or not) within the group (e.g., elaborating on ideas or ignoring suggestions). With regard to the voices reified in the artifacts or environment, I noted when and how focal-group students referred to the written instructions (e.g., for initial direction, for clarification, to support an argument they were making), when and why they moved about the classroom (e.g., to test their program, to interact with other students), and when and how they interacted with material objects and devices provided to them (e.g., observing the functioning of their robot, taking light readings, discussing light reflection and absorption properties of various materials).

This micro-genetic analysis allowed me to build a moment-by-moment picture of the development of the solution. I then used this analysis to develop a broader characterization of the cognitive aspects of student-collaborative problem-solving activity and important aspects of the enacted curriculum that emerged from the interaction of the internally persuasive discourses, both of which contributed to the development of the creative solution.

Findings

Summary

The challenge given to the students was to program the robotic vehicle to move forward until it sensed a darker surface, make a 90-degree turn, back up slowly for one foot, and repeat the program forever. The goal of the lesson was for students to develop their understanding of how the light sensor functions to trigger an event and how to program the light sensor to do so under certain conditions. The triggering sources of black paper provided by the teacher were set on the grey carpet in the front of the classroom. The focal group initially approached the problem by taking light readings of the black triggering surface only. They did not take a light reading of the grey carpet surrounding the sources of black. However, in some cases, the black triggering sources reflected more light than the grey carpet due to the texture of the paper (laminated or not). This was a confounding variable that complicated the problem for the students. They came to understand this problem over time through reasoning activities that included observation, experimentation, argumentation, elaboration, clarification, and play. Student reasoning was directly influenced by the spoken and reified voices present in the classroom. Once the students understood the variable nature of light readings and the role of the carpet in confounding their readings, they enacted a creative solution to the problem. This creative solution was to re-purpose the black cables provided in the robotics kit to serve as the source that would trigger the rest of the light-sensor program.

In this episode, in order to solve the light-sensor problem, the students needed to develop three interrelated key understandings. First, they needed to deepen their understanding of the light sensor from an initial view of it as a simple measuring device to a more complex view of it as a computational device. Second, they needed to develop the understanding that not all similarly hued entities reflect the same amount of light. And third, they needed to re-frame the given problem as one in which the light sensor is programmed to simply react to a black (or darker) surface to an understanding that any number of environmental variables may serve to confound the process (Sullivan, 2008), and, therefore, these variables need to be identified and taken into account.

On the following pages, I present the micro-analysis of the episode. The analysis demonstrates the influence of the various internally persuasive discourses as students engage with them. The episode consists of 17 troubleshooting cycles that took place over a 36-minute period. The troubleshooting cycles ranged in duration from 40 seconds to 4 minutes. Six of the 17 analyzed troubleshooting cycles suffice to illustrate the solution trajectory. The analysis for each troubleshooting cycle includes the following: (a) problem-solving ideas forwarded, (b) student strategy or reasoning, (c) the dialogic influence on the idea, and (d) the appearance and re-appearance of ideas over the problem-solving session. Only ideas and engagement with those ideas as they were voiced during the troubleshooting cycle are included in the table. Double parentheses denote the physical activity co-occurring with the utterance.

Micro-analysis

Students began to solve the problem by deciding on a programming approach. Table 1 presents this initial troubleshooting cycle.

Table 1. Troubleshooting Cycle 1

Ideas forwarded	*Type of strategy and/or reasoning*	*Dialogic influence*	*Appearance of ideas*
E: "Let's just test it out."	Guess and check strategy	Classroom environment, technology designer	
Y: "It needs to be triggered by a black line."	Reference to activity instructions	Curriculum designer	
J: "Okay, we gotta do that first" ((pointing to the solid black paper on the floor)).	Elaboration	Classroom environment	
E: "That's all black. Oh, well. Whatever."	Argumentation	Curriculum designer, Technology designer	First appearance of idea that two light readings are needed

Initially, Esteban suggests a guess-and-check strategy. This idea is influenced by the classroom condition of an open-ended, goal-oriented task. This condition arises as an interaction among the curriculum designers, the technology designers and the teacher's voice. The curriculum designers provided the robotics challenge, which is based on the constructionist nature of robotics technology (Resnick et al., 1996). But they provide no algorithm for solving the problem. The teacher provides the materials in the classroom environment for engaging with the problem, but he also gives them no specific solution instructions. Therefore, Esteban suggests a strategy that occurs to him and is allowed by the design of the technology.

Yolanda is influenced by the curriculum designers' voice as she suggests they follow the instructions that indicate that the light sensor should be triggered by a black line. Janice picks up on this and suggests that they take a reading of the black book cover provided on the floor by the teacher. Finally, Esteban raises the issue that the black book's cover is all black, inferring the need for a reading of the lighter-colored approach surface. His comment seems to be influenced by the curriculum designers, who call for a black line (not a solid block of black), and the technology designers, as the light-sensor function is to detect the difference between light readings from different sources. However, this idea is not taken up by the others, and Esteban does not insist that they take it up. As they take the first light reading, the students evidence understanding of the light sensor as a simple measurement device, useful for reading the amount of light reflected off a surface. They have not yet developed the key understanding that the light sensor is a computational device, capable of comparing light readings to a programmed parameter in order to trigger a programmed event.

The group takes a light reading of the black book cover. They then write a program and send it to the robotic device. At this point, Janice remarks that they need a place to try the program. The students used a specific black source to get the initial light reading, but rather than return to that source to test their program they look for another place in the classroom to test it. This indicates that the students are operating under the idea that all black surfaces will reflect the same or similar amounts of light. They have not yet developed the understanding that not all similarly hued materials reflect the same amount of light. Table 2 presents this troubleshooting cycle.

Table 2. Troubleshooting Cycle 2

Ideas forwarded	*Type of strategy and/or reasoning*	*Dialogic influence*	*Appearance of ideas*
J: "Can we use that?" ((giggles and points at a piece of video equipment underneath the smartboard)). "I wonder if we can use that?"	Utilizing environmental affordances	Classroom environment	
E: "Are you going to use a wire?"	Clarification	Janice's voice	First appearance of the idea of using a black wire as a triggering source
J: "No the thing, that, the string, the thing, I don't know."	Clarification	Classroom environment	
E: "You coulda used the wire."	Utilizing environmental affordances	Classroom environment	Second appearance of the idea of using a black wire as a triggering source
J: "No, not the wire. This. ((bending down and pointing at the video equipment))	Clarification	Classroom environment	

It is during this cycle that the idea to use a black wire to trigger the light-sensor program is first advanced. The idea comes from the interaction between Janice and Esteban as they are influenced by the requirements of the curriculum to utilize a black source and the material culture of the classroom in the form of the black video equipment lying beneath the SMART Board. This exchange also evidences how the students are beginning to jointly develop their shared understanding through tool-mediated communicative and cognitive interaction. This suggestion by Esteban of using a black wire is picked up much later by Janice as an important aspect of solving the problem.

The students test their program and when this program does not work, Janice attempts to articulate why it is not functioning properly. Mr. Smith responds to Janice's comment and lets the group know that he thinks that black material in the grey carpet may be interfering with the functioning of their program. This provides the students with important information that they are not able to initially use. This exchange is analyzed in Table 3.

Table 3. Troubleshooting Cycle 3

Ideas forwarded	*Type of strategy and/or reasoning*	*Dialogic influence*	*Appearance of ideas*
J: "I think it's when it hits like the light— I don't know."	Observation	Technology designer, classroom environment	
E: "When it hits the light. It's not hitting the light."	Elaboration	Janice's voice	
Mr. Smith: "It's hitting the dark lines on the floor."	Refinement	Technology designer, classroom environment	First appearance of the idea that the carpet is interfering with the light reading

In this segment, the dialogic influence on the discussion emanates from observations of the movement of the robotic device and/or from knowledge of how the sensor functions. In this way, the technology designer's voice is the most salient. This is the first time during the problem-solving episode that the students engage with the key idea that other variables may interfere with the functioning of the light sensor.

After several attempts, the group writes a light-sensing program that seems to work. The students notice that the robot runs the algorithm every time it sees a black source. As the students observe the movement of the robot, Janice laughs and puts her black shoe in front of the robot, but it does not trigger the light sensor. Then, Mr. Smith, as he walks around the classroom, playfully triggers their light-sensor program with the tip of his black shoe. While Janice appears to be playing with these ideas, Mr. Smith concretizes the idea of using alternative sources of black through his effective use of his shoe to trigger the program. After this, Janice again puts her foot in front of the robot. Yolanda remarks on the movement of the robot. In this segment, Janice, Yolanda, and Mr. Smith jointly occupy a playful space. They have moved from a serious stance of problem-solving to a playful stance in which they are engaging with the light sensor as if it were a toy. This dual mode of interaction, seriousness and play, is afforded both by the toy-like nature of robotics and by Mr. Smith, who encourages play by taking part in it. This sequence is analyzed in Table 4.

Table 4. Troubleshooting Cycle 11

Ideas forwarded	*Type of strategy and/or reasoning*	*Dialogic influence*	*Appearance of ideas*
E: "Now it's doing it. Now it's doing it every time it finds a black line." ((J puts her foot in front of the robot and laughs.))	Observation	Technology designer	
Mr. Smith: ((walking towards the robot on the floor)). "Hang on, hang on, hang on."	Observation	Technology designer, Janice, Esteban	
J: "Mister, watch out for your shoe." ((Mr. Smith puts his black shoe in front of the robot. The robot senses his shoe and begins to back up)).	Experimentation	Technology designer	First appearance of the idea that one's black shoe might trigger the light sensor program.
J: "There ya go."	Reflection	Mr. Smith	
Y: "It's gonna follow you."	Prediction	Mr. Smith	
J: "Hey look at my shoe." ((Janice places her own shoe in front of the light sensor to trigger the program)).	Experimentation	Mr. Smith, technology designer	Second appearance of the idea of triggering the light sensor with one's shoe.

At this point, the students still need to write a program that performs the entire algorithm specified in the challenge. So, they return to working on their program. Once they have written a new program, they decide to test it out using the teacher-provided black piece of construction paper as a triggering source. Based on the advice of Mr. Smith, they get a new light-sensor reading and program accordingly. When they run the program, they find that the robotic device, rather than moving forward, is immediately moving backward. They go over their program and note that all of the steps seem correct. What the students are lacking here is the understanding that the approach surface (the grey carpet) is reflecting a certain amount of light, and they need to know what that amount of reflected light is in order to correctly program the robotic device. They are assuming that the grey carpet reflects more light than the black piece of construction paper, but that is not the case. They have not yet developed the understanding that environmental variables may confound the process, and they are still thinking about the light sensor as a simple measurement tool, as opposed to a computational tool.

They again appeal to Mr. Smith. He looks at their written program and then he holds the robotic device in his hand and runs the program. He points out to the students that the robotic device is almost immediately going to step two of their program. At this point, Mr. Smith is modeling an inquiry technique to the students that entails close observation of the execution of the program in a neutral environment. He challenges the students to figure out why this is happening. The light reading for the construction paper is 42; they had set the sensor to trigger when it read “less than” 43. Esteban suggests that they try the program with the light sensor set to a lower trigger point of 28, which had worked previously.

They send the new program with a light sensor reading of 28 to the robot. Janice starts to move with the robot to the floor, but Esteban asks for the robot. She hands it to him and he holds the robot in his hands and runs the program. The three students watch the wheels. The students follow Mr. Smith’s modeled procedure of closely observing the execution of the program. Esteban and Janice note that the wheels are now moving in the forward direction. They then both put their hands over the light sensor to see if they can trigger the rest of the program. Here, Janice and Esteban are thinking together while jointly holding the robot and testing the light sensor. This mutual manipulation of the robotic device facilitates a non-vocal cognitive interaction between the two students related to deepening their understanding of the functioning of the light sensor through experimentation.

After this, Janice takes control of the robot and holds it over the carpet and runs the program. She orally references Mr. Smith’s earlier comment about the interference of the carpet and Esteban exclaims, “The floor is the black light!” A non-focal-group student who is working in the front of the room than asks “What is the floor?” and another student answers “The floor is 32.” This exchange is heard by the focal group students. In this sequence, the focal-group students solidify their understanding that the carpet is interfering with the functioning of their robot when it is programmed to read the black source provided by the construction paper. Table 5 presents the analysis of this exchange.

Table 5. Troubleshooting Cycle 15

Ideas forwarded	*Type of strategy and/or reasoning*	*Dialogic influence*	*Appearance of ideas*
E: “Okay, give me, watch, let’s see if 28, remember last time 28 (inaudible) ((J holds the robot while E sends the program. Then moves robot to the floor)).	Prior knowledge, guess and check	Technology designer, classroom environment	
E: ((reaching for the robot)) “No, no, wait. Wait, let me hold it up first.” ((J gives E the robot and he runs the program holding the robot in the air for all to see.))	Observation	Mr. Smith	
E: “See.” (((They watch as the robot wheels move in the forward direction)).	Observation	Mr. Smith, Technology designer	
J: “Now it does it.”	Observation	Mr. Smith, Esteban, Technology designer	
E: “It’s the last one.” ((J puts her hand over the light sensor and E does the same thing. J takes the robot from E.))	Observation	Mr. Smith, technology designer	
J: “Okay, see with the black light, remember? ((J runs the program while holding the robot in her hand, but close to the carpet.))	Prior knowledge	Mr. Smith, classroom Environment	Second appearance of the idea that the floor is affecting the light reading
E: “The floor is the black light.”	Elaboration	Mr. Smith, Janice, classroom environment	
Student 1: “What is the floor?”	Clarification	Esteban, technology designer, classroom environment	
Student 2: “The floor is 32.”	Measurement	Technology designer, classroom environment	
Mr. Smith: “The floor is 32.”	Reiteration	CM2	

E: "The floor is the black light."	Reiteration	Mr. Smith, Janice, classroom environment	

The dialogic influence on student thinking in this segment derives primarily from the design of the technology. This is in large part due to the fact that they are developing the conceptual understanding that light is reflecting off all available surfaces, including the carpet, at varying rates. Observations of and experiments with the functioning of the light sensor are helping them develop this understanding. However, it is also clear to see in this segment that other voices have an influence. For example, Mr. Smith's influence is seen both in Esteban's use of the troubleshooting method modeled by him (hold the robot in your hands and observe the movement of the wheels) and in Janice's recollection of Mr. Smith's earlier comment about the interference of the carpet. We also see in this segment that the student community voices influence the student focal group.

The student's discovery that the grey carpet is interfering with their program causes them to think more deeply about the functioning of the light sensor. Both Esteban and Janice experiment with the robotic device by taking random light readings. At one point, Janice, begins to focus on other triggering black sources in the room. She suggests first that they use her shoe, and then she suggests that they use the black cables available in the Mindstorms kit. The students get a light reading for the cable and program the robot with that reading. This does not work because the students are using a "less than" command in programming the light sensor, which tells the robot to look for a reflection that is less than the reflection of the black cable. Janice seems to realize this when she suggests that they program the robot with the variable of 31. This is less than the reading of the amount of light reflected off the carpet, 32, but higher than the amount of light reflected off of the cable, 20. This suggestion allows them to successfully solve the light-sensing challenge a second time, and in so doing evidence the critical understanding that light is reflected off all surfaces in the room and that one always needs to take into account both the amount of light reflected off the approach surface and the triggering surface. Furthermore, they demonstrate an understanding of the light sensor as a computational device by selecting a modifying variable that falls somewhere between the two readings. Table 6 presents the analysis of this cycle.

Table 6. Troubleshooting Cycle 16

Ideas forwarded	*Type of strategy and/or reasoning*	*Dialogic influence*	*Appearance of ideas*
J: ((At the Mindstorms box, J looks towards E)) "Mira!" ((J holds up a cable from the Mindstorms kit and looks towards Y.)) "We could use this."	Observation	Esteban	Third appearance of the idea of using a wire/cable to trigger the light sensor.
E: "What?"	Clarification	Janice	
J: "Use that. Read it quick." ((J holds the cable horizontally so E can take a reading of it. E takes a light reading of the cable)).	Measurement	Technology designer	
E and Y: "Twenty."	Observation	Technology designer	
E: ((Revises program with new reading and sends to the robot. Students test the robot.)) "It's skipping the line. We have to measure it again."	Observation	Technology designer	
J: ((The students get another light reading.)) "Twenty. Hmmm. Dang, why can't it go on?"	Measurement	Technology designer	
Y: "What's the reading?"	Clarification	Technology designer	
J: ((To E)) "Put it thirty-one."	Hypothesis	Technology designer	Second appearance of the idea that one needs a light reading of both the approach surface and the triggering surface to correctly program the robot.

E: “Thirty-one. Okay now!” ((E sends the program to the robot. The students run the program. It works.))	Affirmation	Janice	
J: “Oh, there we go. There we go. It’s getting it.”	Observation, evaluation	Technology designer, classroom environment	

In this sequence, the students have solved the challenge through creative means and developed a deeper understanding of the functioning of the light sensor, which was the goal of the lesson.

Discussion

A key moment in this episode was the students’ discovery that the carpet was interfering with the functioning of their program. This discovery is what Koschmann and Zemel (2009) would call an occasioned production. It is a discovery that the students did not know they needed to make prior to the moment they made it. Once the students had discovered the confounding role of the carpet in their problem-solving, they developed all three of the key understandings needed to solve the problem. They realized that they needed a light reading of the approach surface as well as the target surface and that they could use the light sensor to discern between the two light readings (light sensor as computational device). They realized that not all similarly hued entities reflect the same amount of light. And finally, they understood that in order to solve the problem, they needed to take into account more than one variable.

Four sets of voices were important in the development of these understandings: (a) the teacher’s voice, (b) the curriculum designers’ voices, (c) the technology designers’ voices, and (d) the students’ voices. Furthermore, as shown in the analysis, the interaction of these voices contributed to the emergence of four critical aspects of the enacted curriculum that contributed to the development of the key understandings and the creative solution: (1) an open-ended, goal-oriented task, (2) teacher modeling of inquiry techniques, (3) provision of tools and an environment that allowed students to move between dual modes of interaction: seriousness and play, and (4) provision of tools and an environment that allow students to jointly develop a shared understanding achieved through tool-mediated communicative and cognitive interaction.

In this episode, students were working towards a goal in an open-ended, goal-oriented way. Their activity was constrained by the parameters of the challenge, and therefore structured, but they were given much freedom in pursuing their solution. Furthermore, the teacher’s modeling of modes of inquiry, which included investigation and reasoning (close examination of the functioning of the robot in a neutral setting) as well as playfulness and bricolage (demonstrated in this episode by Mr. Smith’s use of the tip of his shoe to trigger the program) aided in the development of the creative solution. Levi-Strauss (1966) defined bricolage as the re-purposing of items that are ready to hand in the environment. The creative idea of re-purposing the black cables was an act of bricolage that synthesized the idea of using found black materials — originally suggested by Janice (the video equipment), extended by Esteban (the power cord connected to the video equipment), and then playfully demonstrated by Mr. Smith (the tip of his black shoe).

While playfulness and bricolage are not generally considered modes of inquiry in science, they may well be important modes of inquiry with regard to the development of creative ideas. If this is so, it points to the importance of providing tools and an environment that allows students to move between dual modes of interaction: seriousness and play. In Mr. Smith’s class, the students had a serious purpose, which was to solve the light-sensor challenge, but they were allowed to move between modes of seriousness and modes of play as demonstrated through the teacher’s playing with triggering the robot with his shoe.

Tool-mediated activity was also an important part of the development of the key understandings and the creative solution. The primary mediating tool was the light-sensor-enabled robotic vehicle. The vehicle served both to focus students’ attention and as an object of inquiry. In Troubleshooting Cycle 11, Mr. Smith modeled the technique of holding the robot in one’s hands to test the program. Once he did this, the students (Janice and Esteban) followed suit. Their joint manipulation of the robot was demonstrated when they both put their hands over the light sensor to see if they could trigger the program. They then jointly took light readings of various sources of light in the room and discussed those readings. These activities reflected their growing understanding of the light sensor as a more complicated device. Finally, the activity of experimentation with the light sensor, in concert with Janice's recollection of Mr. Smith's earlier comments, allowed them to construct the understanding that "the floor is the black light."

Implications

In considering the challenge of how to scaffold creative design in collaborative groups, this analysis demonstrates the importance of non-authoritative discourses. The classroom conditions created by internally persuasive discourses open a space for collaborative dialogic inquiry and the creation of new meanings. These conditions allow learners to engage in the reasoning processes (including play) that lead to creative solutions. Scaffolds for creative design then may include introducing an open-ended, goal-oriented task; modeling inquiry techniques that include play and bricolage; and providing the tools and an environment that allow students to move between the dual interaction modes of seriousness and play while jointly developing a shared understanding achieved through communicative and cognitive interaction.

While other researchers have noted student play as an aspect of collaborative creativity (Fernández-Cárdenas, 2008; Vass et al., 2008), this paper introduces the epistemological aspects of play and bricolage as important inquiry techniques in creative work. Play may be considered non-productive, especially in upper grade K12 educational situations. Yet, this analysis demonstrates the efficacy of play and bricolage in developing a creative solution. Therefore, if we are interested in helping students develop the ability to think creatively about problems, we may well wish to model play and bricolage and to create situations where students may fluidly move between serious inquiry and playful inquiry in a collaborative context.

Future research should focus on examining the relationship of play and bricolage to creativity in both the design of classroom environments, and in the design of digital learning environments. In terms of classroom environments, this study indicates the need for an ecological approach in studying collaborative creativity. For example, what are the myriad factors at various levels of institutional influence on the ability of teachers to introduce play and bricolage as inquiry techniques in a curriculum aimed at developing creativity in students? Such a study would help us to understand the impact of broader policy decisions on classroom practice and the development of creativity. This research is particularly important in an era of high-stakes standardized testing. Arguably, schools that focus on teaching to the test are actually engaged in teaching students to comply with authoritative discourses, rather than teaching them to act as bricoleurs or to engage and transform the internally persuasive discourses that animate consciousness.

In terms of studying play and bricolage in digital learning environments, it is likely that many digital environments are already re-purposed by students for various reasons. Understanding how, why, and when students act as bricoleurs with digital materials may aid in the development of scaffolds for further creative activity. Finally, when creativity is a learning goal of a curriculum, designers should carefully consider how to open a space for playful inquiry through the design of the digital learning environment itself.

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References

Bakhtin, M. M. (1981/1930's). *The dialogic imagination* (C. Emerson & M. Holquist, Trans.), Austin, TX: University of Texas Press.

Bakhtin, M. M. (1986). The problem of speech genres (V. W. McGee, Trans.). In C. Emerson & M. Holquist (Eds.), *Speech genres and other late essays* (pp. 60–102), Austin, TX: University of Texas Press.

Bratzel, B. (2007). *Physics by design* (2nd Ed.), Knoxville, TN: College House Press.

Chiu, M. M. (2008). Effects of argumentation on group micro-creativity: Statistical discourse analysis of algebra students' collaborative problem solving. *Contemporary Educational Psychology, 33*, 382–402.

Cole, M., & Engestrom, Y. (1993). A cultural-historical approach to distributed cognition. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 1–46), New York: Cambridge University Press.

Cooper, T. (2004). *A systems-based robotics curriculum,* Unpublished master's thesis, Teachers College, Columbia University, New York.

D'Andrade, R. (1986). Three scientific world views and the covering law model. In D. W. Fiske & Shweder, R. A. (Eds.), *Metatheory in social science* (pp. 19–41), London: University of Chicago Press.

Eteläpelto, A., & Lahti, J. (2008). The resources and obstacles of creative collaboration in a long-term learning community. *Thinking Skills and Creativity, 3*(3), 226–240.

Fernández-Cárdenas, J. M. (2008). The situated aspect of creativity in communicative events: How do children design web pages together? *Thinking Skills and Creativity, 3*(3), 203–216.

International Society for Technology in Education (2007). *National educational technology standards for students*, Retrieved December 23, 2010 from http://www.iste.org/.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39–103.

Koschmann, T., & Zemel, A. (2009). Optical pulsars and black arrows: Discoveries as occasioned productions. *Journal of the Learning Sciences, 18*(2), 200–246.

Kurtzberg, T. R., & Amabile, T. M. (2001). From guilford to creative synergy: Opening the black box of team-level creativity. *Creativity Research Journal, 13*(3), 285–294.

Levi-Strauss, C. (1966). *The savage mind*, Chicago: University of Chicago Press.

Pea, R. (1993). Practices of distributed intelligence and designs for education. In Salomon, G. (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87), New York: Cambridge University Press.

Resnick, M., Martin, F., Sargent, R., & Silverman, B. (1996). Programmable bricks: Toys to think with. *IBM Systems Journal, 35*(3/4), 443-452.

Rojas-Drummond, S. M., Albarrán, C. D., & Littleton, K. S. (2008). Collaboration, creativity and the co-construction of oral and written texts. *Thinking Skills and Creativity, 3*(3), 177–191.

Roschelle, J., & Teasley S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. E. O'Malley (Ed.), *Computer-supported collaborative learning* (pp. 69–197), Berlin: Springer.

Sawyer, R. K., & DeZutter, S. (2009). Distributed creativity: How collective creations emerge from collaboration. *Psychology of Aesthetics, Creativity, and the Arts, 3*(2), 81–92.

Sonnenburg, S. (2004). Creativity in communication: A theoretical framework for collaborative product creation. *Creativity and Innovation Management, 13(4),* 254–262.

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research*, London: Sage.

Sullivan, F. R. (2008). Robotics and science literacy: Thinking skills, science process skills, and systems understanding. *Journal of Research in Science Teaching, 45(3),* 373–394.

Vass, E., Littleton, K., Miell, D., & Jones, A. (2008). The discourse of collaborative creative writing: Peer collaboration as a context for mutual inspiration. *Thinking Skills and Creativity, 3,* 192–202.