The Creative Nature of Robotics Activity: Design and Problem Solving

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Abstract: Learning with robotics through open-ended build and programming design challenges enables the development of creativity in children. Such robotics learning environments encourage three creative activities that are strongly identified with problem-solving and design activity, including problem finding, idea generation, and invented strategies. In this chapter, I present the theoretical grounding for the relationship of creativity to robotics, with a special emphasis on the role of play in robotics learning. I provide examples, drawn from my research with colleagues to demonstrate how children engage in play and creativity with robotics and I discuss how these activities relate to learning. In addition, I provide curricular and pedagogical recommendations to teachers interested in supporting student creativity through a robotics learning unit. Curricular recommendations focus on the types of open-ended challenges teachers may enact across the STEM disciplines. Pedagogical recommendations detail a progressive approach to teaching that emphasizes the facilitating role of students' interest, students' experience, and students' collaborative interactions in learning.
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Introduction

Robotics learning revolves around two activities that are creative in nature: design and problem solving. When students work on a robotics challenge they are involved in the design of a system that includes the building and programming of a robotic device. Designing such a system requires creativity. Oftentimes, students run into unanticipated problems that they must solve in order to create a well-functioning robotic device. Solving such problems also requires creativity. The STEM-based creative activity of design and problem solving have certain attributes that students can manifest in the classroom with the appropriate pedagogical and curricular support. This creative activity of designing and problem solving in a robotics context may lend itself to other, nearby engineering and computing problems, for example building a stable bridge or similar structure, creating a mobile application, or developing an interactive web site. In this way, robotics learning is a creative endeavor with wider application across the STEM disciplines.

In this chapter, I introduce a sociocultural definition of creativity as collaborative dialogic inquiry, which is rooted in the work of Bakhtin (1981). I then discuss the role of play in learning with robotics with examples of such, drawn from my research with colleagues. Next I provide a theoretical view of the creative nature of design and problem-solving activity, I describe empirical findings that support the theory, and finally, I present pedagogical and curricular approach in the instantiation of that activity.

Creativity as Collaborative Dialogic Inquiry

Bakhtin (1981) developed a theory of communication and language development called dialogism. Dialogism has three, inter-related components: addressivity and answerability, heteroglossia, and ideological becoming. Addressivity and answerability refer to Bakhtin's (1986) notion that in any communicative act, the speaker's utterance is influenced by whom she is addressing and the anticipated response of the addressee. In other words, every speaker considers who they are speaking to, prior to the act of speaking. Utterances are formulated with a specific audience in mind. The addressee or audience, thereby, helps to shape what the speaker will say. In this way, utterances among individuals are social and multi-voiced in nature, always containing the voice of the speaker and the anticipated answering voice of the addressee.

Heteroglossia refers to the dynamic and constantly evolving nature of language that is a result of the tension created by the many social languages that make up a national language.

With any national language, there are always variations in language usage at the level of social groups that exist within the nation. These social groups may develop slightly different definitions of particular words, and/or may coin new words, that then become part of the national language lexicon. In Bakhtin's (1981) theory, then, the meanings of words are not fixed, but are ever-changing and dependent on the social and/or ideological position of the speaker of the words and the social context in which they are spoken. Bakhtin describes this phenomenon as the centrifugal forces always affecting any language. At the same time, there are constant centripetal forces that seek to fix the meaning of words in order to create a "unitary language." These centripetal forces are, generally speaking, more institutional in nature in that they seek to reify specific meanings in particular, formal ways. The tension created by these opposing social forces also contributes to the dialogic nature of language. Newer meanings and words are created within the context of this social milieu.

Ideological becoming refers to the development of consciousness within any individual. Consciousness in this regard is the development of one's ontology. Bakhtin (1981) argues that it is through participation in and exposure to various social languages within one's life world that one develops notions and ideas about how the world functions. It is the interplay of ideas espoused in various realms (family, friends, school, religious settings, books, T.V., radio, internet etc.) that one begins to form one's own ideas about life and the world. In this way, ideological becoming is a creative act that emerges out of the "interanimation" (p. 345) of the utterances/discourses to which one is exposed.

According to Bakhtin (1981), the utterances one is exposed to can be characterized as one of two types of discourses, internally persuasive discourses or authoritative discourses. Internally persuasive discourses are utterances and ideas that are dialogic in nature. In other words, these utterances are always informed by the addressee, they are open, dynamic, living, responsive utterances. Authoritative discourses, on the other hand, are monologic in nature. These are dogmatic ideas that have been institutionally reified over time, these utterances are not responsive to the audience, but are always the same, and purport to represent "the truth," – these utterances do not admit the voice of the other in formulation, they do not reflect the perspective of the other, only of the hierarchical authority from which they emanate. In this way, authoritative discourses constitute one-way communication, from the speaker to the addressee. Bakhtin considered these monologic, authoritative discourses to be "dead" discourses. Such a discourse may not be entered into or changed in any way, it must either be accepted or rejected as it is. The clearest example of this type of discourse is religious doctrine and dogma. True believers accept the religious pronouncements as is and attempt to conform themselves to these ideas.

Of these two types of discourses, it is the internally persuasive discourses that account for creativity. As noted above, it is the interplay of various internally persuasive discourses that account for the development of one's consciousness, but, in addition to this, it accounts for the creativity of the individual as manifested in her actions (including her thoughts). Indeed, Bakhtin (1981) argues that "The semantic structure of an internally persuasive discourse is not finite, it is open; in each of the new contexts that dialogize it, this discourse is able to reveal *ever newer ways to mean*" (p. 346) emphasis added. Ever newer ways to mean is reasonably interpreted as the creation of new ideas, the creation of new meanings. In this way, creativity is a fundamental aspect of meaning making and cognitive development.

In Bakhtin's formulation of dialogism it is clear to see the connection between creativity and learning. Like creativity, learning may also be viewed as a process that unfolds through the understanding of "ever newer ways to mean." Creativity as collaborative dialogic inquiry, then, refers to both the process of meaning making, and the making of new meanings through the interanimation of internally persuasive discourses. Again, internally persuasive discourses are the ideas offered from multiple perspectives within a culture or society. An individual takes in these discourses, considers them in light of one another, and, in this way, makes sense of the world. And, at times, the individual creates a new meaning that others have not, yet, considered. Hence, creativity and creative ideas emerge from the social, from the juxtaposition of voices in society as represented in internally persuasive discourses.

In a Bakhtinian sense, voice refers not only to the actual voices of actual speakers, but also to voices as they are set on the pages of a book. Bakhtin was a literary theorist who worked to illuminate our understanding of language and society through examination of literary works. According to the theory of dialogism, the author's voice is reified on the page. Importantly, as Kristeva (1986) has pointed out, the author's voice is speaking within the context of other textual voices. In an elaboration of the theory of dialogism, Kristeva argues that every text is created with other texts in mind, the author is speaking to an audience that is formed, in part, by other authors and other texts. The voice of the author so reified becomes part of a larger, ongoing textual conversation – this phenomenon is known as intertextuality. I argue that this reification of voice takes place not only in a written text, but in the design of tools that people take up and environments they occupy. For example, in the case of robotics construction kits, the voice of the designer is embedded in the design of the tool. Indeed, the designers of the RCX brick, the prototype of all of the LEGO robotics toys, are Mitch Resnick and Fred Martin. In a chapter published in 1991, Resnick and Martin discussed the design of the RCX along the lines of the features of the micro-computer that enable student learning. These features represent the voice, the ideas, of the designers. When children use the robotics kits, they are, in fact, interacting with the voices and ideas of the designers – these reified voices help to shape student activity and learning through the design of the device and what the features of that design makes possible. Norman (2002) calls this the system image. According to Norman, knowledge of how a device works is encoded in the design of the device. A well-designed device suggests how it is to be used – for example, a handle suggests the action of pulling or pushing. The system image is a means of communication between the designer and the user of the device. And, this communication is dialogic in nature, as the designer has well-considered the addressee (the user of the device) when considering how to design it's features.

In the case of robotics, children interact with the voice/ideas of the designers of the device through play. Indeed, the designers explicitly created a device with which children would wish to play. Resnick (2006) has emphasized the role of playful learning in the learning technologies he has been part of creating, which includes the RCX brick (Resnick & Martin, 1991), Pico Crickets (Rusk, Resnick, Berg, & Pezalla-Granlund, 2008), and Scratch (Resnick, et al., 2009). This is an important point to understand, by creating a device with which children can play, the designers have both motivated student learning activity, and also introduced a child-friendly mode of inquiry that may lead to both creativity and learning. Let us now consider play in greater depth.

Play

Role of the Object in Play

One very notable aspect of robotics learning activity is the robotic device itself given its status as both a manipulable and a computational object. The robotic device is similar in size to a smart phone. It is a micro-computer that can understand and execute commands written in various programming languages. One can easily hold the robotic device in one's hand. While it may be slightly unwieldy for young children, children in middle childhood and older youth have no difficulty holding and manipulating the device. Perhaps due to the handiness of the robotic device, children and youth tend to play with it; it has almost a Heideggerian "ready-to-hand" quality in the way that children immediately identify the robotic device as a playful object. Indeed, our research over the last decade, we have repeatedly observed the playful attitude students take towards the device. This playfulness generally manifests in two modes: anthropomorphizing play and analogical play. In the former mode, my research colleagues and I have observed children pick up a robot and make it dance. We have seen children cradle a robotic device like a baby and wonder aloud what to name it. We have heard children scold a robotic device that is not functioning the way the student believes it should (hence the robot is misbehaving) (Sullivan & Wilson, 2015). All of this anthropomorphic play is an example of both imagination (what could the robot be?) and investigation (what is the robot?).

In the mode of analogical play, we have observed children pick up the robot and discuss what other objects the robot reminds them of, for example, children have observed that the robot looks like a drag racing car, a robot with cables attached reminded a child of a purse, yet another child imagined the robot as a dog. These interactions with the robot are not only acts of imagination and investigation, but, also acts of identification. In one instance, a middle-school aged female student playing with one of the small LEGO figurines that come with the robotics kits exclaimed "let's make it a girl" (Sullivan & Wilson, 2015). In making this suggestion, the female student was identifying her own gender with that of the non-descript LEGO toy. She was creating space for herself in, what many view as, the male-identified activity of robotics (American Association of University Women, 2010).

We have also taken note of the role popular culture depictions of robotics play in students' imaginary play in robotics learning settings. Oftentimes, the only prior knowledge children and youth have about robotics is the popular culture depictions they have encountered in television shows or movies. For example, a middle-school aged female student we worked with at a daylong robotics workshop for girls continually referred to the LEGO robotic device as "Evie," based on the the female robot from the Disney/Pixar movie Wall-E, known as Eve. Her reference accomplished two goals, first she was able to playfully identify with the activity through her prior knowledge of the Eve robot character, and second she was able to play with ideas related to the functioning of the robotic device. For example, she discussed tasks she thought her group should program "Evie" to execute.

Play as a Mode of Inquiry in Creative Activity

Both anthropomorphic and analogic play contain aspects of investigation that lead to more robust, playful inquiry that deals directly with conceptual aspects of robotics learning. For example, we have observed students engage in analogic play with the light sensor in such a way as to improve their understanding of how the light sensor functions. The students had programmed the light sensor to respond to a light reading that was lower than a certain threshold. In other words, the sensor was triggered to activate a particular programming sequence when it detected a dark colored object. Through play, the students came to realize they could trigger the light sensor with the tip of their black shoes (Sullivan, 2011). The students developed the analogy of the light sensor as a magnet, claiming the light sensor was following their shoes (see Figure 1). While this analogy is weak (a light sensor would only act as a magnet would if it is programmed to detect a certain reflected reading and programmed to stay on that reading, for example, as in a line following program), it is a beginning analogy that helped the students begin to understand that the light sensor is programmed to respond to certain environmental conditions, which is the conceptual essence of sensors. We have observed that play is an important mode of inquiry for children when they are working with robotics, it stimulates their interest in the topic, allows them to consider robotics in light of prior knowledge, it allows them to identify with the activity (which is particularly important for girls), and it allows them to develop deeper conceptual understanding of the functioning of the robot, for example, the role of sensors in robotics activity.

Figure 1. Students playing with triggering the light sensor with their shoes.

Having defined creativity from a sociocultural lens and considered play as an important element of student creative learning with robotics, let us now consider the specific creative activities that are most closely related with formal robotics study: design and problem solving.

The Creative Nature of Design and Problem Solving Activity

As noted earlier in the chapter, the activity of robotics is comprised of both engineering design and computer programming elements. Both of these activities are creative by nature. In robotics, an important aspect of both designing the robot and writing the computer program, is engaging in problem solving as regards both of these pursuits. Inevitably, students run into issues when they test the robot they have built and programmed. Sometimes students change the physical design of the robot to address an issue and most times, they troubleshoot and revise the computer program they have written. Hence, design and problem solving are foundational activities when working in a robotics learning environment. Let us now consider the elements of design and problem solving as they relate to creativity.

Design

Design has been described by Svihla (2010) as "a ubiquitous activity that occurs in formal and everyday settings, commonly with a goal of making something to be used by someone else” (p. 246). In the case of robotics, students may focus on creating a number of different designs for different purposes. For example, they may design a robotic vehicle or device for use in a scientific investigation (e.g., data collection) (Mitnik, Nussbaum, & Recabarren, 2009), or they may design a machine or vehicle capable of performing a certain type of work or solve specific challenges (Sullivan, 2008, Sullivan 2011), or they may design a robotics system that models a biological system (Cuperman & Verner, 2013).

Schön (1983) has argued that framing a problem is at the heart of creativity in design. Framing a problem refers to seeing the problem from a specific perspective or with a specific lens. For example, the designer can choose to frame the problem from the perspective of a naïve or novice user of a product, and in this way think about the basic functionality of a device. However, one may also choose to frame a problem from the perspective of the nature of the problem to be solved – what are the constituent elements of the problem and how can a design address each? Dorst and Cross (2001) have also argued that creativity in design unfolds as a process of problem framing. In their view, as people work on creating a design to address a specific problem their unfolding understanding of the problem informs the design of the solution. Dorst and Cross term this the co-evolution of the problem and the solution. This process of co-evolution is applicable to a robotics design situation for students. For example, I have found in my research that as students work in the robotics environment, they develop a better understanding of the problem to be solved (they frame or re-frame the problem), and this has an influence on the design of the solution (Sullivan, 2011).

Framing or re-framing of a problem is foundational to design, and it can be thought of as an aspect of apposite design. Apposite design refers to a process in which a designer, or group of designers, arrives at a solution that has been hinted at, but not yet hit upon (hence, it’s apposite nature). Such a solution may arise in the midst of a designing session when a designer has an illuminating thought in which the solution is brought into alignment with the constraints of the problem (co-evolution). For professional designers, this illuminating thought often has antecedents in sketches or discussions (Cross, 1997), but arrives as a centralizing idea in the way that it bridges problem and solution. Akin and Lin (1995) have found that it is when designers are immersed in the triple process of sketching, examining, and thinking that they arrive at novel or illuminating design decisions., which, in many ways rests on the knowledge of the designer. Given this, what are some ways that novice designers (e.g., students designing a robot) can develop the background knowledge and experience to help them develop a creative solution? One way to do this is to become familiar with design techniques. Cross (2004) defines four such techniques as follows:

- *Combination* in design is to take elements of existing designs and combine them to create a new design; for example, a headboard for a bed that has a built-in bookshelf.
- *Mutation* is when one takes one element of a designed artifact and changes it to create something new; for example, arm rests attached to the inside of a car door that have been expanded below to become compartments for small items.
- *Analogy* in design is best characterized by the design of the personal computer. Apple co-founder Steve Jobs conceived of the screen view on a computer as one that should be analogous to a person's actual desktop. In this way, the visual depiction and organizing principle of files and folders for the modern day computer was born.
- *First principles* approach refers to the idea of considering the domain that the designed item itself is a part of – Cross uses the example of sitting posture as first principles for the design of a chair. In using this approach, in order to design a chair, one should first consider the nature of the human body in a seated position – from there, one can develop a design. One problem with the first principles approach to design, as noted by Cross, is that, while it is possible to define first principles for a chair, it may be difficult to define them for other domains.

Each of these four design approaches requires synthesis of ideas. Owen (2007) argues that there are two types of creative activity in design: synthesis and discovery. An approach to design that relies more on discovery than synthesis is emergence. Cross (2004) discusses the idea of emergence, similar to apposite design, as the recognition of new properties within an existing design. These new properties can then be utilized as the basis for exploring new and different designs.

Social and Collaborative View of Design

While a designer may work alone, creativity in the process of design emerges from the social. This is so because as the designer works with ideas, sketches, or techniques, he is always drawing on the internally persuasive discourses that constitute his consciousness. Moreover, it is this consciousness, born of specific social and cultural voices that provide the individual designer with judgment and sensibilities that are then brought to bear on a design. We may think of this judgment and sensibility as the artistic aspects of design – irreducible to technical aspects only because of the very personal and unique origins of ideas. The social and collaborative view of design is also buttressed by the fact that a designer is always interacting with the reified ideas of other designers. For example, in the case of robotics, the student designers are interacting with the designed LEGO materials provided with the robotics construction kits, the design of these building materials cause them to fit together in specific ways, and these constraints suggest specific designs to builders. Within these material constraints, students find ways to realize their creative ideas.

In some ways, we can think of these constraints as an aspect of the "problem" of designing in the LEGO context. Co-evolution of a design, then, works both in terms of understanding the affordances and constraints of the materials, as well as the problem. Let us now consider the creative aspects of problem-solving in greater detail.

Problem Solving

Creativity in problem solving may be manifested in multiple ways. Here we will consider three such modes that are relevant to robotics learning environments: problem finding, invented strategies, and idea generation.

Problem Finding

Similar to the notion of problem framing, problem finding has to do with identifying a problem, formulating an understanding of that problem, and clearly communicating ideas about the problem to others (Runco & Chand, 1995). Csikszentmihalyi (1997) describes the process of problem finding as uncertain and emergent. However, there are things that individuals can do to enhance their problem-finding abilities. For example, Csikszentmihlayi argues that to develop a good formulation of a problem a person should think about it from as many perspectives as possible. In this way, students can create a number of possible paths to solutions to the problem. Moreover, students should not stay bound to one solution to a problem, rather they should evaluate the solution as it is unfolding. This is in the same spirit as Dorst and Cross's (2001) notion of the co-evolution of the problem discussed above. Changes or revisions to the solution should be made in relationship to how well the solution is working out.

In prior research, I found that students developed a creative solution to a robotics problem through this process of co-evolution (Sullivan, 2011). The key to the students' development of a creative idea was their evolving understanding of both the problem they were trying to solve and the functionality of the materials they were using to solve the problem. In this case, the students were asked to write a program that caused a light sensor to respond to specific environmental stimuli. In order to solve this problem, the students in the study first needed to transform their conceptual understanding of the light sensor as a measurement device to a computational device. They also needed to re-frame the problem accordingly; rather than simply measure the amount of light that was reflecting off of one surface, the students needed to measure the light reflected off of both the approach surface and the target surface, and they needed to use the differential between those two readings to program the robot to respond to the smaller (less reflected light) reading. In this case, the students discovered that their target surface was not as dark as required to solve the problem. 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 made this discovery and had developed a greater understanding of how the light sensor worked, they were able to re-purpose materials provided to them in the learning environment to create a darker target surface and thereby solve the robotics challenge. In this case, the re-purposing of materials constituted a creative solution to the problem.

Research on problem finding indicates that the type of problem to be solved will have an effect on the creativity of the solution. For example, ill-structured or open problems require greater problem-finding efforts, and this correlates with more creative solutions, whereas well-structured or closed problems call for more reproductive or algorithmic solutions (Jay & Perkins, 1997; Mumford, Blair, & Marcy, 2006; Ward, Finke, & Smith, 1995; Weisberg, 1986). According to Jonassen (2000), an ill-structured problem has the following characteristics:

- Not all of the problem elements are known.
- There are multiple solutions and multiple-solution paths.
- There are multiple criteria for evaluating the solution.
- Solutions may require personal judgment on the part of the solver.

Robotics challenges may be considered ill-structured in that there are always multiple solutions and multiple solution paths. This is so as equally successful solutions to a robotics challenge may include differently constructed robotic devices and differing computer programs. Because of this, it is possible that students solving robotics problems will be more likely to develop their own solutions to a robotics problem. Amabile (2012) discusses this as heuristic versus algorithmic problem solving. When tackling an open-ended problem, people have the chance to develop their own heuristic approach to the solution; this is often a creative endeavor in itself. Whereas, simply applying an existing, step-by-step algorithm to solve a closed problem does not require much creativity. Let us now consider in greater detail the role of invented strategies in robotics.

Invented Strategies

While many students begin their robotics problem solving efforts using a trial-and-error method (Barak & Zadok, 2009; Castledine & Chalmers, 2011; Gaudiello & Zibetti, 2013; Sullivan & Lin, 2012; Williams, Ma, Prejean, Ford, & Lai, 2008), over time, they move beyond that method and begin to develop more sophisticated approaches to problem solving. Barak and Zadok identified two approaches that they call heuristic searches – defined as approaches that leverage the knowledge students have built about the problem to help them solve the problem. The first type of heuristic search, called the proximity method, involves forward and backward reasoning towards the goal of gradually arriving at a solution. The second approach involves planning that includes modeling and reasoning through analogy or abstraction.

In our work, we also identified students using a modeling strategy to reason about the problem (Sullivan & Lin, 2012). Students used either the robotics materials or their own bodies to simulate the desired movement of the robot. For example, we have repeatedly observed students hold a robotic device in their hands and move it along a surface in the manner they would like to program it to run. In this way, students think through the discreet movements that the robot will execute and they consider how they must program the robot to do so. Oftentimes, students will go back and forth between moving the robot by hand and writing the program. This strategy of simulating the movement of the robot may also take place with a student's hand standing in for the robot. In other words, we have observed students moving their hands in the manner that the robot should be programmed to move – this activity serves the same intellectual purpose as physically moving the robotic device.

The invented strategy of using one's own body to model/simulate the movement of the robot is an aspect of embodied cognition. Embodied cognition is defined by Weiskopf (2010) as the view that "cognitive capacities are shaped and structured by the bodily capacities of a creature, including the sensorimotor capacities that make possible its basic interactions with the world" (p. 295). The theoretical basis for embodied cognition is provided by Barsalou's (2003) situated-simulation theory. In this formulation, cognition is not characterized by, what Barsalou has termed, amodal semantic knowledge (memorized texts), but, rather, by modal recall (simulation) of experiences and actions on a sensorimotor level. Barsalou argues that:

> When the conceptual system represents an object's visual properties, it uses representations in the visual system; when it represents the actions performed on an object, it uses motor representations. The claim is not that modal reenactments constitute the sole form of conceptual representation…The claim is simply that modal reenactments are an important and widely utilized form of representation (p. 521).

Embodied cognition is enabled by robotics devices, and many students will intuitively use their own bodies to reason about how to program the robotic device. In this way, the invented strategy is not only an instance of creative problem solving, but also it may lead to increased learning because it activates real world knowledge and improves memory and recall through physical action (McNeil & Jarvin, 2007).

Idea Generation

A third mode of creative activity related to problem solving is idea generation. As discussed at the beginning of this chapter, the sociocultural approach to understanding creativity focuses, in part, on the discursive interactions among people. Rojas-Drummond, Albarrán, and Littleton (2008) in their research on collaborative creativity in the language classroom have developed a good explanation of how idea generation works in a group:

> Among the common acts present in all the [discourse] data were: joint planning; taking turns; asking for and providing opinions; sharing, chaining and integrating of ideas; arguing their points of view; negotiating and coordinating perspectives; adding, revising, reformulating and elaborating on the information under discussion and seeking of agreements. These data, taken together, suggest that the children engaged in diverse processes of "co-construction" of meaning and knowledge to achieve their goals (p. 186).

The evolution of a creative idea, then, rests in part on an interactive process in which students draw on their own prior knowledge (internally persuasive discourses) and experience to generate ideas and contribute them to the group. These ideas may then be acted upon by others in a number of ways including evaluation, elaboration, clarification, or refutation. Moreover, these ideas may then be considered in light of the other voices that are present in the classroom that contribute to the development of knowledge about the problem. Indeed, in my research (Sullivan, 2011), I have found that a number of voices in a classroom can contribute to the development of students' creative ideas including the voices of collaborative group members, voices of other students in the classroom, the voice of the classroom teacher, the reified voice of the curriculum developers, and the reified voices of the technology designers. It is the interanimation, the juxtaposition of these voices with one another, that may lead the students to the development of a creative solution.

Having considered the creative aspects of the twin robotics activities of design and problem solving, let us now consider how to support student creativity with robotics in terms of curriculum and pedagogy.

Curricular and Pedagogical Approaches to Support Creativity

Robotics Curricula

As we have argued elsewhere (Sullivan & Heffernan, 2016), teachers may use robotics to teach about robotics (first order uses), or to teach about other subjects (second order uses). In terms of first order uses, curricula may focus on issues related to the engineering design of a robotics system, including how to create a working gear system, building stable and functional structures, and the steps one should take to create and troubleshoot the device (the engineering design process) (Heffernan, 2013). First order uses will also focus on teaching about programming the robot and may include instruction on sequencing (Kazakoff & Bers, 2012; Kazakoff, Sullivan, & Bers, 2013), conditional reasoning with sensors (Slangen, van Keulen, & Gravemeijer, 2011; Sullivan & Lin, 2012)), and computer science concepts such as input/output/process, control structures, iteration, and parallel programming (Nugent, Barker, Grandgenett, & Adamchuk, 2010; Sullivan & Lin).

Meanwhile, second order uses of robotics in the curriculum generally focus on modeling or simulating systems or phenomena in the natural sciences. For example, one may use robotics to model biological systems (Cuperman & Verner, 2013) or to teach about forces and motion in a physics context (Mitnik, Nussbaum, & Recabarren, 2009; Williams, Ma, Prejean, Ford, & Lai, 2008). Moreover, robotics may be used to reinforce students understanding of systems in the context of science literacy (Sullivan, 2008).

Curricular Enactment and Pedagogical Approach

Whether a teacher chooses to use robotics to teach about robotics or some other topic, certain elements of the curricular enactment and pedagogical approach are key to supporting student creativity. These key elements are (1) the nature of the problem to be solved; (2) student choice; (3) a non-evaluative stance; (4) the nature of student interactions; and (5) modeling or allowing playful inquiry.

Nature of the problem to be solved. As noted earlier in this chapter, problems may be well-structured or ill-structured (Jonassen, 2000). Many times, in formal PK-12 school settings, children and youth are asked to solve well-structured problems. Well structured problems have the following characteristics:

- All elements of the problem are readily apparent
- Problem solution requires the application of a limited number of rules or principles
- Problem solutions are knowable and comprehensible and all problem states are probabilistic

While it is possible to develop a meaningful and rich, well-structured robotics problem for students to solve (Sullivan, 2005), ill-structured problems are the better choice for enabling creativity. This is so as ill-structured problems support many paths to solution and many correct answers. As noted earlier in this chapter, in a design context, creativity is an aspect of the co-evolution of one's understanding of the problem and the solution. If students are provided with a problem where all elements of the problem are readily apparent, they will not need to evolve their understanding of the problem. Therefore, providing a problem that is robust enough to support many paths to solution will expand the learning space and the learning opportunities for students, thereby improving the chances that students well engage in creative design.

Student choice. To support student creativity, it is critical that students be given some choice in the robotics project they will undertake. Providing students opportunities to choose how they want to work with robotics allows them to follow their intrinsic interests, which fosters creativity (Amabile, 1983). Providing choice does not preclude teacher facilitation or scaffolding, indeed, it is very important that the teacher work closely with students as they evolve the project they want to accomplish. A project based approach to robotics centers on student driven questions about robotics. The role of the teacher is to consider the knowledge, experiences, and interests of the students and build on these through robotics projects that are open-ended, diverse, and challenging. A project-based approach that allows students to explore robotics over time will support student learning, interest, and creativity.

Non-evaluative stance. Another important pedagogical aspect of supporting student creativity is to take a non-evaluative stance. While such a stance is antithetical to the measurement focus of regular classwork, it may be possible to run a robotics project at a time of year when evaluation can be set aside and interest-based learning can take center stage. In the United States, such a time comes in late spring when students have finished taking all of the standardized tests expected of them. During these last six weeks of the year, many teachers are able to undertake more interesting activities with their students. This is a good time to devise a robotics project that will reinforce the learning that students have already done during the year (as in a second order approach), or to simply introduce them to the field of robotics (as in a first order approach). The goal is to allow students to explore, learn, and create without the tension of evaluation and expectation. Hennessey (1995) has shown that student creativity is enhanced when they have a chance to pursue their own intrinsic interest in a non-evaluative, open inquiry. Notably, both of these elements are very important, students must be allowed to pursue their own interests and their efforts need not be evaluated – when these two classroom conditions are met, student's creativity will be realized.

Nature of student interactions. In addition to creating a classroom environment that allows for student choice in a non-evaluative format, to enable and support creativity with robotics, students must be allowed to work together. Students may be supported to work with one another in collaborative groups, and/or they may be allowed to engage in what Zhang, Scardamalia, Reeve, & Messina (2006) have called opportunistic collaboration. This form of collaboration supports spontaneous collaborative interactions among any students in the classroom. Students may choose to work with one another to achieve a specific goal, or one or more students may choose to observe the work of other students in order to learn and develop a better understanding of robotics. The goal is to create an open classroom where students can work with and learn from one another. The operative elements of such a classroom is freedom of movement for students. In other words, while they are working on their robotics projects, students should be allowed to freely move about the room and to speak with any student they choose. While there is potential in this situation for students to veer off course and not tend to the robotics project, there is also great potential for students to engage in deep inquiry and learning. Skillful teachers will find ways to support students in staying on task with their chosen robotics projects.

Modeling or allowing playful inquiry. Teachers should not be alarmed if the robotics learning activities that students engage in resemble play. As has been noted earlier in this chapter, play is a meaningful mode of inquiry in the field of robotics and, I would argue, whenever one wishes to improve or enable creativity. The teacher may also engage in play with the students to aid their learning. For example, in my prior research (Sullivan, 2011), I have witnessed the power of the teacher's playful inquiry to both motivate students to work with robotics, and also in causing them to develop working analogies to more fully explore and build knowledge about the robot as well as the task at hand. In this particular example, the teacher playfully triggered a program on the robot by passing his shod foot below the light sensor affixed to the front of a robotic device. In playing with the robot, the teacher spurred the children to interact in a similar fashion, and, in this way, they developed an understanding of the light sensor as functioning like a magnet, which, as noted earlier, is an accurate analogy when the robotic device is running a line following program (as it was programmed to do in this case).

Conclusion

In this chapter, I have made the case for the creative nature of learning with robotics. Robotics is an interdisciplinary STEM activity, consisting of both engineering design and computer programming content and concepts. Indeed, at the heart of robotics learning is design and problem solving, two activities that have a strong potential to enable student creativity. This creativity may begin through play – as noted above, students may first spend time playing with the robotics devices in order to learn about them or to orient themselves in relation to robotics. Teachers must keep in mind that to actually enact a robotics curriculum that engenders play and creativity, the curricular and pedagogical approaches must include ill-structured problems that students have chosen to tackle due to their own interests. Moreover, the classroom environment should provide students opportunities to walk around and collaborate freely with other students. Teachers should withhold evaluation of students' ideas, and rather encourage and support them in their work, finally teachers should allow students time to play with the robotic devices, and, if so inclined, the teacher may choose to model such playful behavior. If such a playful, open, non-judgmental, and collaborative environment is created, the potential for student creativity with robotics will be high.

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