Developing a Learning Culture of Play for Young Children Through Math and Science

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Abstract: Following a growing body of research on supporting young children's learning through play, in this paper we present two case studies describing the ways we have engaged a group of 18 4-6 year-old children in math and science through play in the context of an afternoon STEM club. Our purpose is to demonstrate some of the key features of a learning environment that balances between academic content and play, and how a learning process with dynamic and triggering ideas can be a productive way to involve young children in activities which share many properties of play. We present examples that illustrate the diversity and the complexity needed for any learning situation, and we highlight the magnitude of children's ability of "doing" math and science that is empowered by their playful nature. We suggest that learning through play in STEM may be productive and engaging for young children.

Keywords: Learning culture of play, pre-school mathematics and science, dimensions of play, authentic learning through play

Theoretical framework

Mathematics and science are often conceived as sociocultural activities in the sense that they are constructions arising from human's effort to solve real world problems or understand the world. This conviction leads to the design of activities for young children that link mathematics and science with real world problems, assuming that this is the way to assign meaning to the two subjects. In his novel 'The Parrot's Theorem,' Denis Guedj (Professor of the History of Science) unveils another side of mathematics for, he claims that mathematics is also a form of (mental) play. Similarly, as stated by Whitton (1998), 'history has revealed that numerous mathematical discoveries […] are the products of mathematicians' playfulness' (p. 474) even though mathematicians often choose more 'serious' words to describe their work. The latter reminds us the work-play dichotomy (Abbott, 1994). Within the framework of inquiry-based learning, the same is supported for the work of scientists and science education (e.g., Saçkes, 2015). This discussion pinpoints the common ground between Papert's (1972) constructionism conviction that we, we should focus on teaching children to be mathematicians (and by extension scientists) rather than teaching children mathematics (and by extension science) and the discussion regarding Play and Learning. In this paper, we aspire to draw examples from two case studies which show that young children find meaning in activities which do not necessarily connect mathematics and science with the real world but simply allow them doing mathematics and science by being exposed to ideas, abstract concepts, riddles, problems leading as play does, to 'hard fun-hard learning' (Papert, 1998) .

Following a growing body of research on supporting young children's learning through play experiences (Marton & Fai, 1999; Fazey & Parker, 2001; Pramling & Samuelsson, 2001; Fazey & Marton, 2002; Samuelsson & Samuelsson, 2002; Samuelsson & Johansson, 2006; Samuelsson, 2006; Samuelsson & Carlsson, 2008; Bulunuz, 2013), the two case studies show how starting a learning process with dynamic and triggering ideas can be a way to involve children in activities which share many of the properties of play. This study builds on the consensus among related literature that 'articulating a single acceptable definition of play is almost impossible' (Chudacoff, 2007, p.1) and that 'play is too complex, diffuse, expansive, and dynamic to allow a unanimously accepted definition' (Gitlin-Weiner, 1998, p.77). Thus, the study builds, as play research does, on the special characteristics of play that distinguish it from other human activities.

The analysis of the examples shows the diversity and the complex texture that needs to be present in any learning situation (as stated by Davis & Sumara (2000)) and a 'fabric of activities' (to borrow diSessa's (2001) expression), that is alternative to what is accustomed for young children. It also highlights the magnitude of young children's ability of doing mathematics and science that is empowered by their playful nature.

Central to our work here is that play is the key element from two different perspectives, which could be characterized as the two sides of a coin. First, we argue that the case studies described (even though they cannot be characterized as play in a strict sense) share the same characteristics with play. Second, these same characteristics on the other hand, characterize the very nature of the work of mathematicians and scientists. Thus, play is the section, which brings together the very nature of mathematics and science and the act of learning mathematics and science. Parallel to the narration we provide, we make connections of different parts of the stories with the characteristics of play and on extension with the nature of scientists and mathematicians' work.

What follows is a detailed account of the two cases, in an effort to highlight 4 of the main properties of play as identified in the literature. Although more characteristics of play and a learning culture of play may be found in the literature, we present and discuss the following four:

1. *Play is situated on uncertainty and thus is unpredictable and surprising.* No child would play a game if it is already known who is going to win the game. The exact same should be applied to learning (in math and science), as the element of surprise is highly connected with constructionist/ constructionism learning (Ackerman, 2017; Author, 2015; Sacristan, 2015; Yiannoutsou, 2015). Further, in the field of sciences, authentic research is always carried out without knowing the end result or the discovery. In fact, a number of discoveries were identified by "mistake" as they were not part of the original investigation.
2. *Play is open to all possibilities* (Samuelsson & Johansson, 2006; Samuelsson & Carlsson, 2008). Because of the feature of uncertainty, to be successful in play, children need to be open to all possibilities. New discoveries in science also proceed in this way and science and math education heavily utilize this element. When, for instance, children build conceptual understanding of a new phenomenon, they need to collaboratively build the new concept in a way that would explain their observations of the physical or mathematical world.
3. *Play is immersive.* This feature of play is closely related to the active engagement of children. As we indicated in the case studies, there were instances that these preschool children were engaged for continuous extensive periods of time, engaged actively within one activity without any destructions. The playful relaxed mode of the activity might have possibly played an important role in this.
4. *Play is cooperative, social and communicative* (Samuelsson & Johansson, 2006; Samuelsson & Carlsson, 2008). No game is fun without playing with others. Popular computer games, for example, are usually played in communities of players. The same applies to authentic math and science. New scientific knowledge is established when accepted by the scientific community. In both cases that we descripted above; knowledge was developed within the group of the children.

The case studies we describe in this paper derived from an afternoon STEM program where 18 children (age ranging from 4 to 6-year-olds) attend on a weekly basis. The program is conducted by a group of researchers (both authors of the paper) having the responsibility of the iterative design and implementation of the activities, as well as a research assistant. All implementations are videotaped with the written consent of the children's parents. Additional sources of data include the children's artefacts and representations, photos or video screen shots of children working, and the authors' reflective notes (from the design, the implementation and the reflection process involved).

The circle case study

This case study describes the involvement of the children in a sequence of activities on circles (duration of 4 1-hour sessions) facilitated by the first author of the paper. A more detailed description of the third and fourth sessions of the sequence is provided.

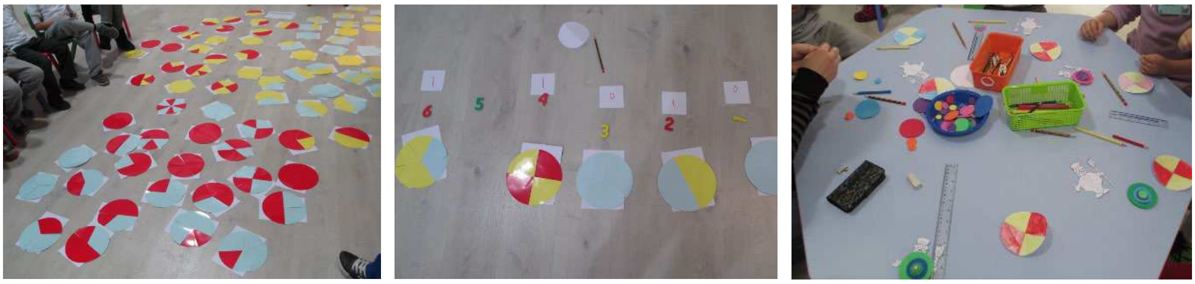
The first session involved free play with a variety of chosen play objects (Figure 1). In the second session, the children were divided in groups and were asked to combine sectors in order to compose circles in as many different ways as possible. The children ended up with many solutions (Figure 2a) and did a number of observations.

(a) (b) (c) (d)

Figure 1. Session 1: Free Play with circles.

In the third session the adult reminded the children that last time one child had noticed that ‘the pieces of some circles are the same’ (same size) and encouraged them to find ways to ‘tidy such solutions up’ (Figure 2b). Only then did the adult realize that the material used did not have 1/5 sectors.

At this point, one child indicated that in the second circle (Figure 2b) he could ‘see a line’ and the children started talking about this line (e.g., ‘it separates the circle into the middle’, ‘… cuts the circle in half’). The children observed that this line also appeared in some of the other solutions and were asked to think of symbols in order to show in which solutions they could see this line and in which they could not. They suggested using symbols ‘1’ and ‘0’ respectively (Figure 2b). The adult grasped the opportunity and asked: ‘Do you think that the missing circle would have had this line?’ There was a common consensus that the circle missing would not have had the line because of the pattern created (‘one circle has the line, and the next doesn’t’). The adult promised to bring them the missing circle the following week to check if they were right.



(a) (b) (c)

Figure 2. Sessions 2 and 3: Problem solving and observing the circle solutions.

The adult then asked the children if they could help her ‘draw’ circle number 4 (Figure 2b) on a paper circle since she really liked it. She insisted that the drawing had to be precise and beautiful. The children suggested the use of a ruler to draw the two lines. Faced with the problem, of guiding the adult where to place the ruler one child suggested ‘folding the paper’. He folded the paper twice for the adult and thus the two lines appeared. All children were given paper circles to fold and draw (Figure 2c).

The fourth session began (and ended) with the whole group. The adult projected the photo illustrated in Figure 2b and reminded the children that she had promised to bring the missing circle. Holding a whole circle, she apologized, in disappointment, for she tried hard but did not succeed in dividing a circle in 5 equal pieces. The children willingly volunteered to help.

The first suggestion thrown on the table was to ‘fold it’. Following the children’s directions, the adult folded it twice. Since, at that point, the circle was divided in 4 pieces, the children suggested folding it once more. ‘Now we have 4, if we fold it again it will be 5’ one child said very confidently. There are no words to describe the surprise in their faces when the adult unfolded the circle and they realized that number 5 was skipped (there were 8 pieces). Thus, as in the case of Play this activity was situated on uncertainty and thus was unpredictable and surprising creating an authentic challenging situation.

Still ‘in shock’, one boy suggested folding it again. The adult started folding the circle for the fourth time but was stopped by a girl that turned to the boy and shouted: “It won’t work. At the beginning, it was 2, then it was 4, then 8. If we fold it again it will be more”. The adult asked the children if they thought she should fold the circle once more. All the children, after the girl’s intervention, agreed it was going to be useless. This specific incidence is the most apt example of the way in which the activity was (as Play is) cooperative, social and communicative.

At this point, it felt like a deadlock. The adult suggested observing in the photo projected (Figure 2b) the third circle. One child said that there were lines from the ‘round of the circle to the middle’. This led the children to suggest taking a ruler and drawing lines from the circumference to the center of the circle (the center being, as the children explained, ‘the point created in the middle of the circle when folded’). Following the children’s directions, the adult drew one line (Figure 3a) and the children suggested drawing a second line from another point of the circumference to the center. This was the next challenge. Where was this point?

The adult showed some of the constructions they had made when they were playing with the geoboards (Figure 1a, 1b). They remembered that when they wanted their sectors to be equal, they had to count the pins at the circumference of the circle. This turned the attention of the children to the circle’s circumference. One child suggested that we had to ‘measure the outside of the circle’ and another child suggested we use a ruler. This idea was rejected because ‘the ruler could not bend’. So, the children suggested that we needed to use rope. The adult brought some rope and was guided to use it to measure the circumference of the circle. Therefore, the adult ended

up holding a piece of rope that had the length of the circle's circumference and asked "Now what?" One child suggested cutting the rope in 5 equal pieces. Since time was running out the adult decided to tell the children that she knew how to do this and demonstrated the procedure. Thus, she ended up with 5 equal pieces of rope and once again asked 'Now what?' One girl suggested putting one of the 5 pieces of rope 'around the circle starting from where the first line was drawn' (Figure 3a). 'The end of the rope will show us where to draw the second line' one child added. The procedure was repeated (always with the instructions of the children). The result is illustrated in Figure 3b. The immersive nature (one of the properties of play) of the children's engagement was apparent The procedure lasted approximately 50 minutes, with no child complaining about being bored or about the task being hard. At the sight of the adult holding the circle (Figure 3b) and announcing: 'we did it', all the children spontaneously stood up and started jumping up and down in excitement.
Even though the story ended at this point, we could not omit the following detail. The following year the adult attempted to do a similar activity with a new group of children. When she introduced the challenge of dividing the circle into 5 equal pieces, one boy asked for a geoboard. The adult asked 'Why". The boy said: 'Give me one and I will show you.' The adult gave the child a geoboard. The child took the circle and 'nailed it on the geoboard (Figure 3c). He turned to the adult and said: 'Done! Now all we have to do is count the pins around the circle.' So, (again as in the case of Play) the activity was open to all possibilities.

(a) (b) (c)

Figure 3. Session 4: Dividing a circle into 5 equal sectors.

The compass case study

This case study describes 2 1-hour sessions with the children in a sequence of activities on magnets, facilitated by the second author. The sequence started with a plenary discussion, by announcing the children the adult's discovery of a letter under the door indicating that there was a hidden treasure somewhere in the room. He asked the children about their ideas as to what they could all do to find the treasure.

A child suggested that treasures are usually hidden under an "X" so we ended up looking for an X in the room. Despite our efforts we found none! Then a second child suggested that it might be helpful if we could find a map for the treasure. Unfortunately, the letter was not accompanied by a map. Then, a third child indicated that Dora's (the explorer) cousin, Diego sometimes has in his backpack a compass. Maybe a compass could help us. That idea provided us with a possible solution: we had some compasses!

Following instructions, the children got into groups of two, one of the children in each group had a compass in her hand and the other child should watch the compass carefully. Every time they heard a sound from a drum, they froze and pointed to the direction of the compass' needle. By the third time they froze, children realized that they were all pointing to the same direction, which made them move towards that direction hoping to get a "stronger" signal for the treasure. However, the 5th time we froze, the compass of the research assistant in the room was pointing to a completely different direction. The research assistant, as directed prior to the session, was next to a large metal pillar, which attacked the compass' needle. So, as in the case of the Circle Case Study the activity was situated on uncertainty and thus was unpredictable and surprising creating an authentic challenging situation worth discussing.

What followed is an apt example of how the children worked collaboratively thus indicating that, as in the case of Play, the activity was cooperative, social and communicative. The first child to respond suggested that the compass must had been damaged. This was an acceptable idea, which was also easy to check and fix. She offered the research assistant her compass to try it out. Therefore, she got up, and went to stand next to the research assistant, only to discover that her compass was showing the same wrong direction. Then, a second child offered his compass, only to find the same issue. At that point, children suggested that this should have not been a malfunction. A child then proposed a different idea: “maybe”, he said, “there is something in the wall that makes the compass point to that”. The children agreed that this was a possible cause of the situation.

That gave us the opportunity to try various materials out. The plan was to introduce children to a specific experiment and to provide them with the materials to test their projections. We provided children with a worksheet (Figure 4) with a rectangle in the middle to place various materials and 6 circles around the rectangle to place six compasses. As soon as the compass’ needle stopped moving, they recorded its direction on the paper. By the end of the 1-hour session, all children teams tried out at least 5 different materials, and recorded their observations.

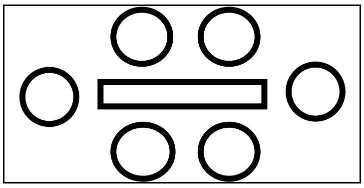


Figure 4. The worksheet for the compass experiment.

The next session, a week later, started with a new game: children were asked to build a long train (Figure 5). Every child was given a wooden block, a magnet with the same length as the wooden block and a piece of tape. They all taped their magnet on the wooden block. The adult placed his wagon in the middle of the plenary and asked from the first child to add her/his wagon. A girl placed the second wagon which was attracted by the first one. The same happened to the third and fourth wagon but surprisingly this did not happen to the fifth wagon providing a new and surprising challenging situation indicating that the activity (as play) is open to all possibilities. The fifth wagon would not attract to the rest of the train. The solution was given by another child: “try to turn your train the other way around!” The fifth child complied, and the wagon was attracted to the rest of the train.

Figure 5. The train we built.

Before moving with the rest of the wagons, the adult decided to pause the activity and he gave each child 2 magnets to try this out. This helped children realize that magnets can attract each other on the one side, and only if you turn one of the magnets the other way, then the magnets will repel.

After a quick reminder of what we had done the previous time, the adult asked children to observe the worksheets from the last session organized in three different categories: (a) materials that did not interfere with the direction of the compass’ needle; (b) the ones that seem to alter the direction of the compass’ needle, but there was not a particular pattern (magnetic metals); and (c) the ones that altered the direction of the compass’ needle in a particular way: attract the tip of the compass’ needle in one end of the material and repel it in the other end (magnets). The adult presented children with the three different groups explaining the ways he organized them, and asked children why they thought this happened (Figure 6).

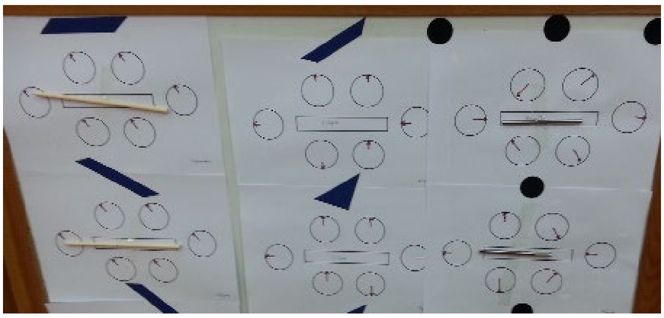


Figure 6. The children’s recordings organized and displayed by the adult.

In the conversation that followed, the children put together all the pieces of the puzzle cooperatively. This ability of the children to join all the pieces of the sequence to address the original question raised shows the immersive nature of the activity. One child proposed a novel idea: “maybe” he said, “the [needle of the] compass is magnetic”. This led us to the conclusion that the compass’ needle has some magnetic features, which probably explained the reason why the research assistant’s compass’ needle pointed to a different direction.

Having finished the discussion, the children were again divided into pairs, and got a compass. This led children to the north wall of the room, where they discovered 3 envelopes with instructions to make their own compasses.

Discussion

In this paper we shared the approach of guided play, identified as a balance between freedom and structure or free play and direct instruction (Weisberg, Hirsh-Pasek, & Golinkoff, 2013; Weisberg et al. 2015). This places a great deal of the teaching challenge in the role of the adults to structure the play environment in such a way that would provide children with opportunities to meaningfully engage in learning, but also leaving the control to the children within the environment (Weisberg et al. 2015) to engage in a playful mode. As we have shown in our case study descriptions, the adult’s role in this has two functions: (i) carefully prepare the environment beforehand by designing appropriate activities and (ii) provide scaffolding to children’s actions while the play unfolds (Fisher et al., 2010). We suggest that this approach can be an effective and possibly more developmentally appropriate learning approach for preschool children (Weisberg, et al, 2015). Agreeing with Weisberg, et al, we also suggest that guided play approaches provide learning situations that encourage children to become engaged and active in the learning process, which is aligned by a growing body of research (e.g., Marton & Fai, 1999; Fazey & Parker, 2001; Pramling & Pramling-Samuelsson, 2001; Fazey & Marton, 2002; Lindahl-Samuelsson & Pramling-Samuelsson, 2002; Pramling-Samuelsson & Johansson 2006; Pramling-Samuelsson, 2006; Pramling-Samuelsson & Asplund-Carlsson, 2008) that suggests that learning and play share many features for preschool education.

In this paper, we focused our presentation on examples that illustrate the diversity and the complexity needed for the learning situation we studied with an understanding that this complexity is shared with all learning situations. Throughout this complexity, however, we seek to highlight the important role of the particular dimensions to play that were embedded in our lesson designs, which enabled children to actively engage in math and science. Active learning can only take place if a curriculum identifies what is to be learned as well as pays close attention to how children feel while learning (DiSessa, 2001). To accomplish this, however, is a difficult task, mainly because this ‘fabric’ of learning requires freedom, spontaneity, exuberance, fun, ownership (characteristics associated with play) that do not sit happily or naturally within a context geared to prescriptive programs (Abbott, 1994). Through a case study description of stories of young children ‘doing’ math and science, in this paper we demonstrated some of the key features of a learning environment that balances between academic content and play. A key idea of this derives from Papert's view suggesting that diving into unknown situations is a crucial part of learning (Ackerman, 2017). In our stories, this idea is the section, which creates a common ground between learning and play and allows the balance between play as the children’s way of learning and academic achievement.

In the description of the two case studies, we also highlighted the magnitude of children’s ability of “doing” math and science which was actually empowered by their playful nature. Towards this end we suggest that the ways in which a Learning Culture of Play allows children to construct understandings of abstract mathematical and scientific ideas (e.g., what the structural features of a circle are, how a compass works) and vice versa; how learning in math and science can support the development of a Learning Culture of Play.

Further, we content that these case studies highlight that learning through play in STEM subjects for young children may be productive and engaging for them, even for concepts, skills, and epistemological understanding that are traditionally part of the content of formal education in older ages.

Overall, our content from this work follows Pramling-Samuelsson & Johansson’s (2006) call for a paradigm shift in the way play and learning are perceived both in research and in preschool practice. We suggest that the two cases from early childhood STEM education that we described, combined a number of features of play with active learning engagement of children. Towards this direction, our main idea is that play and STEM subjects in pre-school share a number of characteristics which make possible to suggest that authentic play, as children experienced it, is a form of science education in STEM. In the two cases that we described in this paper, we demonstrated some of the key features of a learning environment that balances between academic content and play. However, we do not suggest that we have covered all features of guided play. As Weisberg, et al (2015) suggest, more research is needed on these issues to determine how the ways features of play may be meaningfully incorporated in educational settings. It is possible, for instance, that pedagogical choices could vary across content areas as well as age groups.

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Identity Negotiation Through Creative and Collaborative Expression: Middle School Girls' Experiences in the Converge Art and Science Program

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Abstract: This study traces the evolving perspectives and practices of two middle school girls, who identify as Latina and Afro-Latina, over 13 months of participation in a transdisciplinary art-science program. Despite prevalent assumptions that science and art are incompatible, the thinking practices utilized in these domains intersect in important ways. The program under study leveraged the commonalities among performing arts, science, and engineering by engaging youth in the collective development of performances about social and environmental issues. Longitudinal ethnographic case studies were utilized to understand the complex nature of each participant's experience in the program, including her lived (enacted) and storied (narrated) relationships with science. The ultimate goal of this study was to understand the potential of a transdisciplinary art-science approach to expand possibilities for Black and Latinx females in science education. Findings suggest that leveraging art and science can provide a means for identity negotiation through creative and collaborative expression.

Introduction

Transdisciplinary education has been gaining momentum with researchers and practitioners around the world (e.g., Marshall, 2014). By recognizing the value of multiple viewpoints and practices, transdisciplinary approaches provide a way to unsettle disciplinary boundaries (Finch, Shapiro, & Moreno, in press). Supporting plurality in this way has the potential to expand possibilities for youth in school and better support their current and future selves outside of school.

Challenging our understandings of what practices and identities are legitimate through this approach may be especially fruitful in science education, which has historically appreciated a narrow range of epistemologies, axiologies, and ontologies (Quigley & Herro, 2016). With this finding in mind, it is also critical to recognize that the individuals performing and interpreting practices in science classrooms are inhabiting bodies that are raced and gendered, social ascriptions that have histories in and of themselves (Gutiérrez, 2013). Further, the topics studied, and the materials and tools used in science education carry their own histories, some of which are affiliated with White and Asian males (e.g., computer science, physics) (Kafai, Fields, & Searle, 2014). The interactions among individuals and artifacts in science education manifest in concrete ways, resulting in the ongoing underrepresentation of individuals identifying as Black, Latinx, and Native American and female in science, technology, and engineering fields (National Science Foundation, 2017). This phenomenon begins as early as middle school when many of these youth begin to disconnect with science (Calabrese Barton et al., 2013).

Previous scholarship demonstrates that leveraging art and science can support the developing interests and identities of Black and Latinx youth, and those of whom identify as female in particular, in science education (Kafai et al., 2014). In transdisciplinary art-science spaces, youth have more opportunities to engage in imaginative thinking and collaboration, as well as other transdisciplinary thinking practices (e.g., critical thinking, communication) (Quigley & Herro, 2016). Encouraging imaginative and creative thinking, in addition to critical thinking, in science education is especially important for youth who have developed a distanced relationship with science. These thinking practices highlight the value of *youths'* unique ideas and contributions, which are informed by their intersecting identities and lived experiences. When engaging in imaginative and creative thinking, youth leverage their knowledge and resources, which, in turn, creates a sense of ownership and connection with the disciplines in which they are engaged (Kafai et al., 2014). Further, valuing the transdisciplinary thinking practices of collaboration and learning from others promotes a sense of community which has the potential to disrupt competitive and authoritative thinking found in some science classrooms, which can deter individuals whose practices do not resonate with this approach (Archer et al., 2017).

In light of this scholarship, this study investigates how long-term participation in a transdisciplinary art-science program influences the identities of two female youth, who identify as Latina and Afro-Latina, with science, and specifically how these identities relate to their perceptions of transdisciplinary thinking practices. Youths' relationships with science are enacted (lived) in their interactions and utterances in the program.