

WORKING TOWARD A MATHEMATICS LITERACY THAT ENGAGES CREATIVITY, IMAGINATION AND A MATHEMATICAL IDENTITY

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This project aims to introduce a new paradigm for mathematics literacy. By integrating computational thinking and coding into curricular units from The Algebra Project, we engaged middle school students in creativity, imagination, and self-expression in the mathematics classroom. We refined instruments to measure the development of student voice, agency, and belongingness. In the context of the mathematics classroom, there is potential for an earned insurgency to arise when these attributes of mathematical identity are amplified, leading students to engage in a learning community that rejects the repressive logic of the current racialized, classed, and otherwise oppressive mathematics education.

INTRODUCTION

One of the most persistent failures of the U.S. educational system is the ongoing presence of an achievement gap between Black and Hispanic students and their White and Asian counterparts. A similar persistent achievement gap exists between low-income families and high-income families, although this income achievement gap in education has been measured to be twice as large as the racial achievement gap, and it has shown to have grown since the 1970s (Sacks, 2016). With the *model minority* (Wong, 2015) stereotype being applied only to Asians, it is clear that in our current system, the more alienated and stigmatized you feel in the greater society, the worse you will do in school.

In spite of this, in our research we have found that the academic setting can be a place where one can combat current negative societal impacts, rather than reinforce them. In previous papers, we have explored how supporting a student's cultural forms of orality (Shaw et al., 2021) and their individual sense of agency (Shaw et al., 2023) can lead to more positive engagement and better outcomes. While students are in school, they are still working through the existential challenges they face outside of school, and we have found that students can become more engaged academically when they feel that their voice and their capacity to engage in self-affirming initiatives is validated within the classroom.

MATHEMATICS ANXIETY AND STEREOTYPE THREAT

The authors of the paper "Mathematics anxiety and stereotype threat" demonstrate that how a student looks at themselves cannot be divorced from how they view a field like mathematics when it can easily be perceived as a threat to their attempt to build a positive self-image (Maloney et al., 2023). Those who already feel undervalued and underappreciated in society can experience increased anxiety in

academic pursuits like mathematics, since the perception is that failure in fields like mathematics will justify their existing societal devaluation with reinforce negative implications about their intellectual abilities. In our research, we have found that one of the ways to break out of this familiar anxiety is by encouraging a paradigm shift in the mathematics classroom. The shift begins by asking both the student and the teacher, “Is mathematics a field that allows for creativity, imagination, and self-expression?”

This is a loaded question because most will assume that mathematics was never intended to be any of those things. One can argue that mathematics is seen more as an analytical pursuit than a creative one. In fact, you could go so far as to argue that the way it is usually taught may even discourage creativity, while instead encouraging a rigid conformity to applying formulaic solutions. And yet professional mathematicians have long argued that mathematics is indeed a creative, imaginative and expressive field (Halmos, 1968).

In Forest Park Middle School (FPMS) in Clayton County, Georgia, USA, we have demonstrated that mathematics can be taught with a pronounced creative, imaginative, and expressive component. FPMS is divided almost evenly between Black and Hispanics, 48.1% and 45.3% respectively, with very few White and Asian students. By incorporating curricular units from the Algebra Project (AP) and computational thinking activities developed at Kennesaw State University (KSU), we have introduced a new mathematics literacy paradigm.

MATHEMATICS LITERACY AND A MATHEMATICS IDENTITY

The Algebra Project considers mathematics as an important type of literacy for the modern age (Moses & Cobb, 2001). In language arts, it can be argued that literacy enhances a student’s ability for creative and imaginative self-expression, leading to the ability to develop a broader understanding of one’s own identity. Similarly, we believe opportunities for creative mathematical expression broadens a student’s understanding of their own math identity, affirming the power of their own intellectual agency. This leads to what Bob Moses called an intellectual earned insurgency (Moses, 2009). An *earned insurgency* involves overcoming a repressive system whose logic led its victims to believe in the system’s legitimacy, making it difficult for its victims to resist it. Such an insurgency is necessary for those who are intellectually alienated and stigmatized in society.

In a mathematics classroom, students can be confronted with the idea that their own creative, imaginative, and discursive agency can overthrow how they normally think of mathematics. Seeing mathematics as an activity that allows them, collectively, to look at the world creatively, and to be imaginative as they discuss and apply mathematical ideas, opens the students up to seeing a mathematics that belongs to them, when too often it is seen as only belonging to others (Delpit, 2012). The more that working with mathematics involves personally meaningful expressions, the more the students can feel ownership over that work, and over mathematics itself by extension.

Treating mathematics as an expressive tool which can be used as a creative formalized version of what students do informally through orality, can help students engage in mathematical activities on a more personal level. Walter Ong (2002), in his book *Orality and Literacy*, explains how engaging in formal written systems restructures thought processes and expands an individual's modes of consciousness. Ong argues that “speech is inseparable from our consciousness” (p. 9) and writing does not “reduce orality but enhanced it” (p. 9), leading to the conclusion that providing different systems (or modes)

of creative self-expression to an individual helps them grow intellectually, and in their conception of themselves. We see this as implying that when students are encouraged to engage in creative and imaginative mathematics activities that involve discourse in a meaningful way, by using mathematics as an expressive medium they are developing their intellectual agency in mathematics, as they develop new ways to communicate meaningful ideas. And in this way, they can identify with mathematics in a more expressive sense, which we argue leads to a more positive type of mathematics identity.

OPPORTUNITIES FOR CREATIVITY, IMAGINATION, AND SELF-EXPRESSION

The model of mathematics education that we have developed focuses on fostering student growth through three key avenues of engagement: student voice, agency, and identity. Our model recognizes that the traditional approach to teaching mathematics does not fully engage most students or allow them to thrive. We conceive of the teacher's critical role in the mathematics classroom, in large part, as creating the space for students to engage, express, and develop their voice, agency and, in turn, their identity as mathematics learners. The concept of voice refers to providing students with the opportunities to express themselves in their own words and ways that resonate with their life experiences. Agency refers to not only what students are able to do in the classroom but also what they are willing to try to do which goes beyond their past performance. The space that teachers create should allow for student self-expression of both voice and agency as expressions of students' imagination and creativity. And this self-expression enhances the students' sense of their ownership over mathematics and their sense of identification with it.

Our model is connected to the Algebra Project's 5-step curricular process that involves: (1) engaging in a shared event to model mathematically, (2) representing the event pictorially, (3) informal *People-Talk* discussions about the event, (4) formal *Feature-Talk* discussions about the event, and (5) symbolically representing the event using equations. This process encourages students to talk and write about their shared experiences in the classroom in their own words, creating a space for students to fill with their own thoughts and their own ways of expressing themselves. In short, with their own imagination and creativity.

The strength that all students bring to their schooling is their ability to communicate in their own language, in their own way. People-Talk, the 3rd step, is a means to culturally and experientially embed the language of the students in the mathematics classroom. By allowing students to draw upon their own experiences and backgrounds, it bridges the gap between their daily lives and the classroom, making mathematics more relevant and engaging.

In Feature-Talk, the 4th step, students reflect on their shared experience and decide upon the critical features of the event that symbolize and ultimately explain the mathematics they develop. In the 5th and final step in the curricular process, students' use of their own symbolic tools is also part of students' expanding agency in the mathematics classroom. When students have honed their symbolic representations/tools to the point where they support the same type of mental work that the conventional symbols of mathematics do, not only do they achieve a deeper understanding of the mathematics they study, but they are in a position to recognize for themselves the agency they have acquired in the mathematics.

The last thing that students expect in the mathematics classroom is an opportunity for their own self-expression. The traditional mathematics classroom is typically built around rules and procedures, leaving little room if any for unique self-expression and imagination. This alternative approach that we are proposing encourages students to experience the paradigm shift we discussed earlier, along with the intellectual earned insurgency.

INTELLECTUAL AGENCY THAT INVOLVES MINDLESS AND MINDFUL AGENTS

The People-Talk and Feature-Talk activities take advantage of the interactive nature of the discourses that students can engage in through small group discussions and through discussions held amongst the entire class. However, one of the challenges involved in learning mathematics in this way is that this type of engagement and interactivity suddenly becomes completely absent when students are trying to work through a mathematics problem on their own, without the group context. However, adding computational thinking and coding activities can help with this by introducing the paradigm of what we call the “mindless agent” interaction as a comparable alternative to the “mindful agent” interaction.

Interacting with another individual is what we call a “mindful agent” interaction, and it offers all of the People-Talk and Feature-Talk benefits that we have been discussing. However, once a student gets to the 5th step in the AP’s curricular process, the challenge is to use the symbolic representations and the formalisms involved in ways that continue to allow for creativity, imagination, and self-expression. Yet this task becomes harder during an activity like a test when there are no other mindful agents to interact with. This raises a learning progression question concerning how to help students think about using mathematics formalisms more abstractly. We argue that introducing the concept of a “mindless agent” is a key solution to this problem, and this type of introduction can be done in a natural and authentic way by overlapping traditional mathematics with computer science (CS) and computational thinking (CT).

The concept of interacting with a mindless agent involves finding an algorithmic approach to applying a formalism so that you can explain it to an entity like a robot, who can then apply it mechanically. CT activities like decomposition, pattern recognition and abstraction lead to algorithmic thinking. And CS microworld environments allow students to use algorithmic principles to write scripts and programs to control virtual objects involving equations and formalisms. We, like Seymour Papert (1980), define a microworld to be a digital environment where students have tools that they can use in creative ways to explore concepts related to a specific conceptual domain. A microworld might involve programming, and it might not, however, in our research we have created a programming microworld that is focused on exploring mathematics and CT concepts and activities. Papert built his microworld using the Logo programming language. Ours is built using Python. In both cases the environments support open-ended explorations in mathematics by the student through interacting with a mindless agent in that environment that speaks the programming language in question.

The 5-step curricular process takes the student from a concrete experience to an abstract symbolic conceptualization. However, the 5-steps don’t explicitly address where the student goes from there. We see the need to deepen the learning experience by having the student find new interactive ways to explore the symbolic conceptualization and play with it until the student is comfortable using it creatively, imaginatively, and for self-expression. We see that microworlds can serve as a type of

epistemic playground, where students can write sentences to a mindless agent in symbolic equations or programs that reflect those equations in some way, and in this way interact with enactive-iconic mathematical representations in that environment. In other words, a student can take an idea that involves something like fractions, or linear equations, or any math idea, and then make changes to the parameters involved in the formalism in order to achieve a creative or imaginative outcome in that environment. In this way, an idea that started with a concrete event and then became a symbolic conceptualization, is now being used to make something happen concretely again by interacting with a mindless agent in a virtual environment. We see this as an experiential learning cycle that takes the 5-step curricular process to a conclusion that involves getting the student to the point where they can use a mathematics formalism that they have just learned in a concrete way that connects to the next concrete experience that leads to the next new abstract mathematics formalism. The following is a representation of this complete experiential learning cycle.

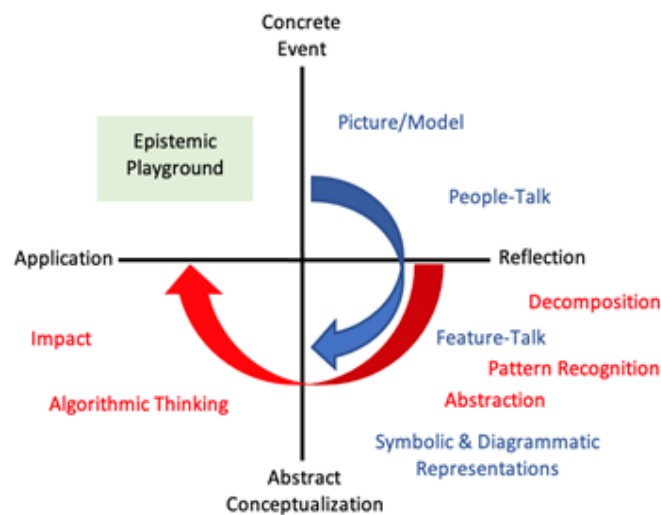


Figure 1: The epistemic playground in our experiential learning cycle.

CLASSROOM OBSTACLES TO CREATIVITY, IMAGINATION, AND SELF-EXPRESSION

Before they participated in our program's intervention, the students at FPMS had limited success in mathematics, as evidenced by their below-average proficiency and testing scores. While in 6th grade, 73% of the students performed as beginning-level learners; the lowest level, which is well below grade level in state testing. However, that percentage dropped to 60% beginning-level learner in the second year of the intervention, an improvement of 13%.

One of the ongoing challenges faced by teachers was getting buy-in from the students, who were often distracted by the socioeconomic conditions they faced outside of the classroom. These challenges and the lack of buy-in caused some students to resist applying themselves when doing the creative work of drawing mathematics diagrams, engaging in discussions, or thinking outside of the box. At times, some students were hesitant to speak with their peers about their shared experience during People-Talk sessions. Students were faced with having to work collaboratively in a mathematics class for the

first time in some cases, so teachers had to focus on finding new ways for motivating and encouraging students to try something new.

The mathematics teachers in our program succeeded at this by fostering a sense of the classroom being a safe collaborative space and a space where it is not a problem to make a mistake as you try something new. The teachers also learned to meet the students where they were, connecting the students' own way of expressing daily experiences to the mathematical ideas being presented. One teacher had the students discuss what transportation method they used to get to school, and then had the students turn that discussion about getting back and forth to and from school into a set of algebraic expressions. Through discourses like this about lived experiences, teachers made connections that stimulated intellectual engagement in mathematical terminology even when there was a language barrier to overcome. The teachers reported that there were many challenges, but that many positive outcomes were also experienced with this approach, and that they saw improvements in motivation, encouragement and excitement for learning.

BELONGINGNESS AND IDENTITY

Prior research has established a relationship between belongingness and self-efficacy, ability beliefs, and improved academic performance (Yeager & Walton, 2011). While it is important to provide interventions for and measures of belongingness and identity, existing measures may be inadequate. Good et al. (2012) offer the following definition of belonging, "sense of belonging, as we conceptualize it, involves one's personal belief that one is an accepted member of an academic community whose presence and contributions are valued" (p. 702). Students in the Algebra Project classroom may have a positive experience of the intervention and yet feel alienated from the mathematics academic community. The intervention seeks to help students become co-authors of the mathematical concepts they are learning, an experience different from the procedural approach to learning mathematics that students usually experienced. Discord may occur if students still feel alienated from prior learning experiences even if they feel accepted in the learning community that forms in an Algebra Project class.

A closer look at the elements of the Algebra Project may explain this phenomenon. During the process that takes students from People-Talk to Feature-Talk, the project encourages a form of code-switching that honors the students' logic and symbolic representations while also allowing the student to translate that into more common mathematical representations. In this sense, the student may see the difference between the representations and value both. They can operate in the world of common mathematical representations while acknowledging that that world is not native to them. Since the Algebra Project students are separate from and part of the mathematical academic community at the same time, measures of belongingness that focus on a specific academic community may provide inaccurate results. Instead, we must consider asking whether students feel they belong in *this* math class and whether they perceive they belong in the larger community of people who communicate concepts mathematically.

Another potential avenue to explore this is to pair the study of belongingness with the study of uniqueness. Koydemir et al. (2018) hypothesized, "a personal sense of uniqueness would be positively related to authentic living and negatively related to self-alienation" (p. 3). Their study showed a

personal sense of uniqueness was positively related to authentic living which is positively related to well-being. We hypothesize that uniqueness (and its relationship to authenticity) and belonging may more appropriately explain the set of internal characteristics that the intervention hopes to affect. That is, as students look back on their experience with this project, they may appreciate their own sense of uniqueness through their engagement in People-Talk, while at the same time appreciating how Feature-Talk fosters a burgeoning sense of belongingness to a community of people who communicate mathematically.

EVALUATION APPROACHES

Program Evaluation has been defined as “the systematic collection of information about the activities, characteristics, and outcomes of programs, for use by people to reduce uncertainties, improve effectiveness, and make decisions.” (Patton, 2008, p. 39) In collaboration with researchers, program evaluators seek to examine the components of innovative models such the one proposed in this paper. There are several constructs of interest for doing that in this project, including classroom-level constructs such as teachers, school context, and implementation, and student-level constructs like student voice, agency, and identity.

To examine classroom-level constructs, we see the need for a collection of qualitative data, including pre- and post-implementation interviews with teachers, classroom observations, and an implementation checklist. Pre- and post-implementation interviews are used to gather data about teachers’ prior educational and professional experiences, along with their thoughts about the Algebra Project’s 5-Step Curricular Process, the school context and environmental factors, any potential obstacles, and the pedagogies teachers used to engage students in prior years. Classroom observations provide insight into how teachers implement the 5-Step Process and students’ response to those activities. Through observations, we are able to see if and how teachers create the space for students to engage, express, and develop their voice, agency, and identity. The enactment checklist provides insight into what activities teachers engaged in on non-classroom observation days. Through enactment checklists, teachers share their lesson plans, activities, worksheets, project criteria, and their reflections about the week’s activities.

Along with pre- and post-implementation interviews with teachers, and classroom observations in general, our analysis also looked at student-level data focused on voice, agency, and identity. Student voice data included student-created artifacts where students express themselves in their own words and in ways that resonate with their life experiences, either written or orally. Agency is understood through artifact interviews with students. Identity is assessed through semi-structured interviews, asking students about their feelings in their math class and whether they perceive that they belong in the larger community of people who communicate concepts mathematically. We found modifications were required to existing sense of belonging scales in order to increase their validity for our uniqueness, identity and belonging measurements.

CONCLUSION

In this project, our aim was to introduce a new mathematics literacy paradigm to a typical school mathematics classroom. We integrated the Algebra Project’s 5-step curricular process along with computational thinking and coding activities, with the goal of engaging middle school students with

new opportunities for creativity, imagination, and self-expression in a mathematical context. We believe this leads to an experiential learning cycle, and to opportunities for creative mathematical expression that broadens a young person's development of voice, agency, and positive mathematical identity. Done in the context of formal mathematics instruction, we have found that this model provides the potential for an *intellectual earned insurgency* to arise, one that rejects the repressive logic of the current racialized, classed, and otherwise oppressive mathematics education.

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