Supporting Orality and Computational Thinking in Mathematics

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The pedagogy of The Algebra Project introduces mathematics concepts to students through experiential activities that students then analytically examine using a combination of both informal and formalized language. In this paper, we identify how cultural forms of orality can be supported within this discursive approach, while also introducing computational thinking activities that are particularly constructive. We argue that when cultural forms of orality are left unacknowledged and unexplored, they can lead to issues that have a negative effect on both student engagement and comprehension. But when explicitly supported in the specific ways that are outlined here, new opportunities arise for student-led creative and pragmatic inquiries that have the potential to deepen the level of student engagement and comprehension.

The process of schooling fails many mathematics students by overlooking opportunities to engage or blatantly rejecting their orality, a cultural asset of many youth. Yet mathematics education has long identified the importance for student-student discourse in learning mathematics and promoted pedagogical strategies such as small group and whole group discourse routines (NCTM, 2014). Both Piaget and Vygotsky make central the importance of interaction in their theories of learning (Steffe & Thompson, 2000), yet the 5-step curricular process (Moses & Cobb, 2001) developed by The Algebra Project (AP) is among few pedagogical practices that intentionally bridge from experientially grounded, ordinary discourse to that regimented discourse (Quine, 1981) of the mathematics discipline. AP's work cycle provides multiple opportunities for learners to move between internalization and externalization (Papert, 1990), bridging the partial stories of each of the sociocultural and the constructivist perspectives on learning.

In this paper we report our approach to instruction in mathematics and computer science that engages students' orality grounded in the historical work of AP, arguing our approach develops both mathematical reasoning and computational thinking. We present a developmental cycle that builds from student assets of culturally rich orality to develop mathematical abstractions and literacy. The development cycle engages children's propensity to imagine, create, reason, and discuss.

The Paradigm of Orality to Literacy, Instead of Orality vs. Literacy

Our research addresses the manner in which schools fail many young people influenced by deeply meaningful cultural forms of orality. By itself, the experience of orality does not need to be treated as an educational deficit; rather, when seen through the appropriate pedagogical lens, orality can be treated as an asset toward producing a rich discursive academic environment. Our argument is that orality can provide constructive building blocks to literacy within various disciplines unless it is ignored or mistakenly pitted as an incompatible stumbling block to literacy.

This second position is such as that taken by Orr (1987) in a well-known book, *Twice as Less*, "For students whose first language is BEV [Black English Vernacular], language can be a barrier to success in mathematics and science" (p. 9). By examining schoolwork, Orr determined the use of nonstandard English led to misunderstandings. Orr suggested a connection between students' nonstandard use of particular "prepositions and conjunctions that in standard English distinguish certain quantitative ideas" (p. 9) and their misunderstandings of certain quantitative relations, resulting in "a lack of distinction between addition and multiplication and between subtraction and division and thus to a confusion between 'twice' and 'half'" (p. 13), for example.

Orr's argument is firmly in the camp that views features of certain language patterns within African American cultures as an impediment to learning, reflecting the deficit paradigm that views orality as having negative implications (at least academically) on particular students. In *Orality and Literacy*, Ong (2002) provided an important counter to this way of thinking. He identified African Americans as a "dominantly oral culture" (p. 43). And although not focused on African American culture, he addressed commonality across primarily and secondarily oral cultures. For Ong, critiques of phrases such as "twice as less" exemplify a misconception that sees patterns of orality as being prelogical or illogical "in the sense that oral folk do not understand causal relationships" (p. 56).

Ong (2002) made the case that there are specific and necessary imperatives in oral cultures that do not follow certain textual patterns, reasons for which do not rule out logical and sophisticated conceptualizations as claimed by Orr (1987). In this line of reasoning, Ong (2002) states that,

> The elements of orally based thought and expression tend to be not so much simple integers as clusters of integers, such as parallel terms or phrases or clauses, antithetical terms or phrases or clauses, epithets. Oral folk prefer, especially in formal discourse, not the soldier, but the brave soldier; not the princess, but the beautiful princess; not the oak, but the sturdy oak. Oral expression thus carries a load of epithets and other formulary baggage which high literacy rejects as cumbersome and tiresomely redundant because of its aggregative weight. (p. 38)

So, the word "twice" used with "less" may be no more a misunderstanding of how subtraction differs from multiplication than how the use of double negatives imply that the speaker doesn't understand the difference between a negative and a positive. In the phrase, "twice as less," just like in the phrase, "ain't no sunshine," the first word may be there to confer a greater emphasis and importance on the second part of the phrase.

Ong (2002) extended his critique of views like those presented by Orr,

> You cannot without serious and disabling distortion describe a primary phenomenon [like orality] by starting with a subsequent secondary phenomenon [like a math concept] and paring away the differences. Indeed, starting backwards in this way—putting the cart before the horse—you can never become aware of the real differences at all. (p. 12)

In other words, if you fail to understand or acknowledge the key role that orality plays within some cultures, unnecessarily conflicted assumptions can result, negatively affecting the students involved. One must make note that orality, in Ong's words,

> can be quite sophisticated and in its own way reflective.... To assume that oral peoples are essentially unintelligent, that their mental processes are 'crude', is the kind of thinking that for centuries brought scholars to assume falsely that because the Homeric poems are so skilful, they must be basically written compositions. (pp. 55–56)

Moreover, we believe deficit views toward oral cultures also feeds into an anti-constructivist viewpoint, in that it sees the context of orality as something that needs to be removed to reach some type of false *tabula rasa* goal, instead of constructively building upon oral conceptions in the quest to help the student become more literate.

In our approach, orality provides a perfectly suitable starting point for a type of informal mathematical discourse with the students that leads to a more formal, literate discourse over time. This approach follows W.V. Quine's (1981) treatment of constructivist mathematics learning as grounded in language discourse, with mathematics as an especially rich conceptual language that provides connections to both informal and formal conceptualizations. Ong (2002) explains that orality is often more "situational rather than abstract" (p. 48), and in our research, we've seen the need to incorporate or create experiential curricular material that has an appropriate situational context like that produced within the Algebra Project curriculum. In this pursuit, we incorporate constructivist computational thinking and programming activities that utilize enactive and iconic elements to provide youth the opportunity to explore mathematical ideas in imaginative and creative ways.

The Algebra Project Pedagogy and the Five-Step Curricular Process

For some thirty odd years, the Algebra Project (AP) and Bob Moses, its founder, have struggled with issues of what to teach and how to teach in order to raise the floor of math literacy for those students most disenfranchised in the U.S. public school system. AP developed and refined its culturally centered approach to mathematics education in schools with majority African American populations in southern districts like Jackson, Mississippi and Atlanta, Georgia, as well as in urban districts like Chicago, Illinois and San Francisco, California. The culturally based pedagogy they developed draws from the critical role that social facilitation and social identity serves in communities of color, where collaborative models are especially prominent. This is evident, for example, in the "call and response" cultural patterns that make their way into the classroom, but it is also connected to the need to cooperatively and collectively solve persistent challenges in resource-poor communities. Because of this, AP has found that this population of students is more receptive to collaborative learning models than to the more individualistic and competitive approach that is the standard in U.S. schools.

The collaborative approach developed by AP involves students working together in small groups that report out to the rest of the class as they make progress. The breakout groups help develop a sense of ownership over the ideas the students address in the groups, and they help facilitate giving different students various leading roles on a rotating basis within the group, using their orality to help them develop a sense of the importance of their agency and their voice. AP's 5-step curricular process gives students many opportunities for this type of positive affect when studying mathematical concepts, and we are finding the same to be true when we integrate concepts from computer science. The AP curricula that emerged, and most importantly, the project's curricular process, is the synthesis of three distinct lines of thought: (1) experiential learning, (2) agency first through student voice, and (3) the regimentation of ordinary discourse—seeing children's orality as an asset in their learning.

Experiential Learning as Mathematization. From its inception, Moses' development of AP has been continuously informed by his participation in the Civil Rights struggle in Mississippi and the community organizing tradition which arose out of it. "The Algebra Project is first and foremost an organizing project—a community organizing project—rather than a traditional program of school reform" (Moses & Cobb, 2001, p. 18). So how AP elicits the classroom participation of students who have been convinced that they cannot do mathematics is of prime importance. What would a good community organizer do in a community feeling powerless? They would encourage a sense of shared agency within which to develop a sense of empowerment. Doing this in a school setting implies the need for a domain for doing mathematics that involves a shared concrete experience that students can collectively work together to address. Learning mathematics in this model primarily consists of students mathematizing the events of their shared world, their communities, the places where they felt most expert in the company of their peers. This perspective over time developed strong connections to the experiential learning models of Piaget, Dewey, Lewin, and Kolb.

The basic sequence was simple. Collectively, students engaged in some physical activity designed to be intrinsically interesting. They tried it. They thought and talked about it. They came up with ways to understand and improve the experience. And finally went back to play and experiment with it again. This was the basic experiential learning cycle built into AP curriculum units: collective activity around a shared event, reflection upon the event, a conceptualization of key aspects of the event, and finally an application of the learned concepts to begin another cycle of experiential learning.

The Regimentation of Ordinary Discourse. Moses was also deeply influenced by the mathematical logician W.V. Quine. Quine's (1981) perspective that the foundations of mathematics—arithmetic, elementary logic, and elementary set theory—begin in the regimentation and structuring of ordinary discourse fit naturally into a classroom practice grounded in the natural language discourse patterns of students, i.e., their various cultural forms of orality. Students' ordinary discourse was referred to as People-Talk because that was the way ordinary people talked among themselves when not a part of a specialized academic or professional group. The structuring of ordinary discourse was identified as Feature-Talk. Feature-Talk served to bridge the gap between the everyday discourse of students and the abstract symbolic representation of the conceptual language of mathematics. Mathematics—like other artificial languages, e.g., coding—is a language that is read and written but never spoken. Feature-Talk provides a means for students to read and write abstract symbolic representation (equations, inequalities) in an interpretative and hence meaningful fashion.

How the Voiceless Find their Voice: Community Organizing in the Classroom. The primary tool of community organizing for the Student Non-Violent Coordinating Committee (SNCC) in the Mississippi theatre was first and foremost the meeting. The meetings were where the voiceless found their voice. Community members, the sharecroppers, first met in small groups and focused on the concerns that they brought with them. Next, the small groups brought their concerns to larger groups through the voices of the sharecroppers who first raised them. This was a practice that Ella Baker brought to SNCC, SNCC brought the practice to the Mississippi Delta, and AP brought the practice to the mathematics classroom.

By first meeting in small group and discussing the shared experience of the class, students who thought they had nothing to contribute to the mathematical conversation found they did have thoughts and opinions that they could share and indeed were eager to share. Discourse in a mathematics classroom may not come easy at first, but once it gets started it can be hard to stop, like the way static friction is harder to overcome than kinetic friction. As an empirical matter, we have seen that once students get engaged around a shared experience they find intrinsically interesting, they are both willing and able to discuss, investigate, and even entertain conjectures about the whats, hows and whys of the event. Students in AP classrooms don't just talk about the event; they capture what they find most important in pictures and in text. The typical AP classroom is plastered with chart paper covering the wall. Students, typically in small groups or teams, capture their thoughts about their experience on chart paper, publish it by hanging it on the wall and report out to the whole class on its contents. As with the community meetings of Mississippi sharecroppers in the 1960s, this process is wholly owned by the students themselves.

The Development Cycle of Voice – Agency – Identity through the 5-Step Process. There is a dynamic here which is meant to capture the conceptual growth and development of students who move through the 5-step curricular process. The students begin together with a (1) shared concrete experience. Because all students have access to thoughts and opinions about this concrete event, all students have a place and a voice at the table. The students (2) draw pictures of the event, write, and speak about the event first at the intuitive level of everyday discourse, (3) People Talk. The 5-step process engages the strengths that students bring both from their natural language abilities and from the natural informal logic that is embedded in the language that they speak. They then engage in (4) Feature-Talk through the consideration of those features or attributes of the event that they consider most salient and interesting. From an identification of important features, they move on to consider how those features are related. And finally, they try to capture these features and their relations in (5) iconic or symbolic representations of their own construction. These representations are set to the task of problem solving and are refined by students until they can effectively handle the same representational tasks using the conventional symbols of mathematics.

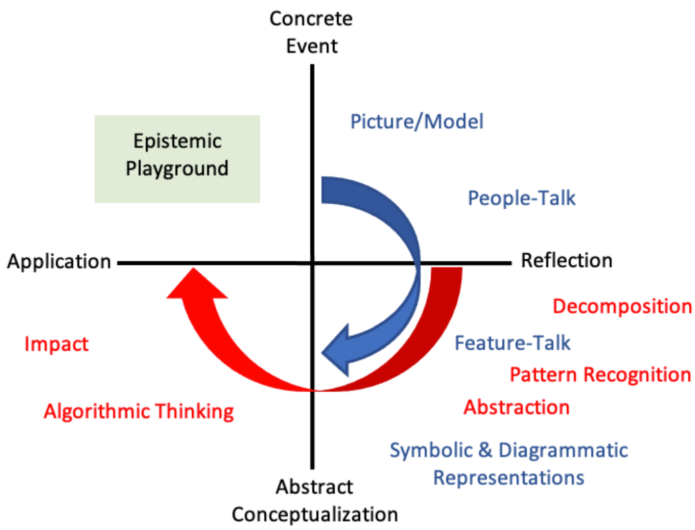
Within the 5-step curricular process, mathematics is generated and learned as a collective enterprise. Students come to understand the notion that the knowledge they build is not just for themselves, because it ultimately benefits their team and their entire class. To achieve this collectivism, the AP follows what is now a fairly well-known trend in discourse rich mathematics classrooms, with addition of specific details that draw upon orality and build both individual and collective voice. Mathematical work follows a pattern of individual thinking (production), small group work (publication), and finally whole group discussion (peer-review).

Computational Thinking Within the Orality to Literacy Paradigm

To the AP's 5-step curricular process we add computational thinking (CT) activities and skills. These activities introduce collaborative technological tools and their created artifacts to the classroom in constructive ways. A CT process is outlined as defining the problem by decomposing it, solving the problem by recognizing solvable patterns in the problem, and analyzing and understanding the impact of a problem's solution. Thus, CT includes a set of skills we describe as decomposition, pattern recognition, abstraction, algorithmic thinking, and analysis of impact.

In the AP curricular process, the second step is for students to create models of a shared experience through a drawing, graph, or other representation. While doing this, students can identify subcomponents and/or subsystems within their model using the CT skill of *decomposition*. As students move into the People Talk, students use the CT skill *pattern recognition* identifying patterns in the subcomponents. During Feature Talk, AP's aim to discover and define features abstractly parallels the CT skill of *abstraction*. The final stage of the AP curricular process, representation, provides opportunity for the next CT skill, examining symbols *algorithmically* to address how the symbolic form can be used to produce various outcomes. This CT stage involves using technology to programmatically and algorithmically examine abstract ideas using technical and computational tools, such as a microworld. This is an important added stage to AP's curricular process, allowing for further examination and analysis of an abstraction's *impact*.

The Developmental Cycle and the Microworld. Learning a new idea, from a constructionist (Papert, 1990) viewpoint, is an active process characterized by a developmental learning cycle. When the learning process occurs within this cycle, a person is actively integrating the concept they are learning (or constructing) into their own broader intellectual understanding of a related domain. This active engagement from the learner is critical to the learning process and is exemplified as the student does the work of exploring, analyzing, and probing a new idea that emerges from a concrete experience until it becomes familiar enough to be abstracted or generalized for them so that they can apply the concept appropriately in whatever task is subsequently given to them. The student's exploration, analysis, and examination that makes up the student's intellectual work is, by and large, an internalized process that is aided by different types of educational resources. The diagram at right gives a picture of how we see those resources playing their part when the developmental cycle of the AP along with CT interventions are fully in place.



The introduction to the conceptual material starts with a concrete event and modeling that event in a physical way, such as through a picture, chart, or graph. This opens the door to informal and formal discourse about the event that directs the student into progressively deepening reflections. CT activities are introduced during these reflections that assist the student in representing the mathematical features abstractly and symbolically. In this way, these steps offer students a bridge from a concrete external event to something that involves internalized conceptual understandings. When students are not provided with such a bridge, we believe many students fail to build an appropriate intellectual scaffolding a mathematical concept may require.

Even though building an internalized abstract conceptualization is often the goal of academic instruction, it is insufficient if it is not ultimately developed into a form that can be articulated and/or applied by the student in a subsequent activity. In other words, the student needs to be able to take what they have internalized, and then externalize it in an appropriate way. And for this to happen, the student needs to be able to put what they have learned into a systematic and algorithmic form. That is to say that the student needs the ability to move through a set of steps that shows how the concepts that they have learned can produce various types of impacts. From a constructionist viewpoint, this latter stage of the learning process is no less important than the former stage, because once again, if the student is not an actively engaged participant in this latter stage, then even the best instructions given may not lead to a successful outcome. And we believe that actively engaging the student in this latter process requires allowing the student to play with the concepts they are learning, and this means allowing them to engage their imagination and creativity during this part of the learning process.

Going straight into a testing phase after learning some new abstract idea is not the best way to help students get a firm grip on concepts that may be difficult to thoroughly digest. Students need an appropriate opportunity to chew on an idea rigorously before being tested on how well they have digested it. Therefore, our final quadrant in the map of the developmental learning cycle is the epistemic playground. This playground is the place where a student is given the opportunity to explore and experiment with the ramifications of the new concepts that they have constructed. We believe all learners need this, but in many educational settings, this type of activity is not provided. For some students, these explorations might involve entirely internalized cognitive musings, and as such, they are able to chew on the ideas without the help of the teacher. But we believe that with an appropriate microworld, the playground can be an externalized activity that makes it easier for the teacher to actively instruct the students on how to engage in this critical final stage of the developmental cycle.

We, like 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. If the domain is fractions, then students in the playground can creatively arrange fractions in various ways and see what happens to their properties and values as they move numbers around. If the domain is geometric shapes, then the students have tools which allow them to create various lines, shapes and angles in ways that allow them to test the geometric principles of the geometric forms they have just constructed. A microworld might involve programming, and it might not. For instance, Papert argues that Logo is a microworld because it allows its users to easily create simple structures, test ideas, and get meaningful feedback without needing to know many of the programming language's details or commands. On the other hand, a language like BASIC, and programming environments using BASIC, are not microworlds because even though BASIC is not a complex programming language, specialized and sophisticated knowledge is required before a student can use it to create simple structures, test ideas and get meaningful feedback.

We believe that adding CT activities in the specific ways we have been outlining can help engage learners in the full developmental cycle shown in the above diagram when learning mathematics. The cycle involves internalization and externalization, reflection and application, discourse and reasoning, rigorous analysis and abstraction, as well as imaginative and creative play. An interesting feature about the developmental cycle as we have outlined it, is that it starts with a shared concrete event, and when it progresses all the way to the epistemic playground students are able to engage in explorations and experiments that can also be shared as concrete events with other students. The developmental cycle begins with a community of learners sharing things through their various cultural forms of orality, and it ends that very way as well.

Conclusion

In schools across the world, students come with various backgrounds and cultural influences. When educational practices disadvantage certain cultural influences over others unnecessarily, the result is a type of cultural chauvinism that has no place in a multicultural society. And what our research further suggests is that culturally insensitive educational practices are also a missed opportunity to engage in an effective educational developmental cycle. When a student’s own particular forms of cultural orality are treated as an essential part of a discourse rich curricular process, such as the one from AP that we have presented here, the result is a learning environment that has fewer barriers to the student becoming engaged. And greater engagement in the informal dialogue (People Talk) opens the door to stronger engagement in the formal dialogue (Feature Talk) when the student begins the steps toward decomposition, pattern recognition, abstraction, and understanding symbolic representations.

Papert (1980) indicated that the cultural context plays an important role in an individual's educational development, and he argued that this broader sociocultural component must be addressed in the basic constructivist paradigm:

> All builders need materials to build with. Where I am at variance with Piaget is in the role I attribute to the surrounding cultures as a source of these materials. In some cases, the culture supplies them in abundance, thus facilitating constructive Piagetian learning. For example, the fact that so many important things (knives and forks, mothers and fathers, shoes and socks) come in pairs is a 'material' for the construction of an intuitive sense of number. But in many cases where Piaget would explain the slower development of a particular concept by its greater complexity or formality, I see the critical factor as the relative poverty of the culture in those materials that would make the concept simple and concrete. In yet other cases the culture may provide materials but block their use. (pp. 7-8)

The poverty that Papert is talking about here is not in the culture, per se, but instead in the materials, or tools, available to the learner to appropriately build upon the conceptual underpinnings that they start with, to develop intellectual structures that represent literacy in any particular field. In this paper, we have argued that when existing advanced technologies, such as microworlds, are properly used, they can indeed serve as constructive materials that students can use in more creative and imaginative ways. The creative and imaginative approach brings to mind the idea of an intellectual sandbox where an engaged mind is encouraged to play with an idea until they have begun to develop a sense of familiarity and ownership over that idea.

In this paper we are arguing for a learning paradigm that involves a particular type of developmental cycle. The cycle starts with a concrete event or activity that can be shared amongst a community of learners. And then within that learning community a discourse begins that is informed by rich and cultural expressions of orality that increase engagement and emphasize the importance of every student's voice being heard. From there, a process of decomposition, pattern recognition, and abstraction follows. When these stages involve the use of computational thinking paradigms, students can interact with the formalisms and abstractions they have been learning about within a technological and programmatic microworld. The microworld serves as a conceptual playground where the students can externalize and experiment with the concepts to better understand and digest them. And this playground ultimately leads the students to making new constructions that can become as concrete to them as the original event that set this cycle into motion.

This cycle involves both externalized and internalized processes that work together. Without a balance between these two types of engagement, the developmental cycle is incomplete. In our view, many, if not most, students are faced with an incomplete developmental cycle when it comes to mathematics instruction, as well as other formal areas of instruction. And students are often unsuccessful because of this. When true balance is achieved in this learning paradigm of the developmental cycle, students enter what Ackermann (1990) called a cognitive dance:

> My claim is that both 'diving in' and 'backing up' are equally important in getting such a cognitive dance going. How could anyone learn from their experience as long as they are totally embedded in it? There comes a time when one needs to translate the experience into a description or a model. Once built, the description gains a life of its own, and can be addressed as if it were 'not me.' From then on, a new cycle can begin, because as soon as the dialogue gets started (between me and my artefact), the stage is set for new and deeper connectedness and understanding. (p. 10)

To truly serve students from diverse backgrounds in modern classrooms, we need to provide them with the entire developmental cycle, which involves shared community building activities and events, the embrace of orality supporting informal discourse, rich decomposition and abstraction developing formalized discourse, and finally a sandbox where ideas about formalism and algorithms can be turned into intellectual constructs with which to play. *In short, children must have a mathematical learning environment in which they imagine, create, reason, and discuss framed in a cycle of abstraction, formalization, and language regimentation that begins and ends with the concrete.*

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