"…to understand is to discover, or reconstruct by rediscovery, and such conditions must be complied with if in the future individuals are to be formed who are capable of production and creativity and not simply repetition."

Jean Piaget (1948)
To Understand is to Invent: The Future of Education

Algebra and Analogies for Kids

By Jerry E. Fluellen Jr.
Educational Psychologist

A Teacher Inquiry Plan
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Abstract

To reflect on the mathematics achievement of children engaging "Algebra and Analogies for Kids," the teacher researcher will explore the following inquiry: <u>What happens when kids display analogical thinking in an algebra project?</u>

Specifically, the study will examine the reasoning of five children in portfolios of best works and selected performance assessments. Their intellectual products will provide evidence of analogical thinking. Additionally, the target participants will engage replicated Piagetian tasks for analogical reasoning in mathematics vis a vis his reflecting abstraction model.

Teacher Inquiry

What happens when kids display analogical thinking in an algebra project?

Background

Jean Piaget's studies on reflecting abstraction included research on analogical thinking of kids engaging mathematics. He explained what it meant to understand an object or idea deeply.

In plain English, a tennis ball illustrates his reflecting abstraction model.

The tennis ball is yellow, round, rubber-like, and about the size of an orange. These qualities can be observed directly. Less obvious is the hollow. Combined with observable qualities, the hallow ball can bounce. When struck with a racket, the tennis ball can be aimed to hit a spot on a court. Once in play, the ball can bounce back and forth between two rackets and off the surface of the court. But the tennis ball also shares qualities with a baseball, basketball, football, and many other balls used in sport.

In the language of Piaget, the observable qualities of the tennis ball rate as **empirical abstraction**. Bouncing is **reflecting abstraction**, and bouncing back and forth on a court rates as **reflected abstraction**. Relationships between the tennis ball and other balls sharing the qualities of buoyancy and game play rate as **metareflection**.

As Robert L. Campbell explains in his introduction to *Studies in reflecting abstraction,* “Piaget proposes a basic developmental process called *abstraction reflechissante* (literally, reflecting abstraction). At the same time he regularly calls attention to a higher-order refinement of this process: abstraction reflechie (literally, reflected abstraction). In turn, *abstraction reflechie* has its own higher-order refinement which Piaget calls *metareflexion* (metareflection).”

Analogy, in Piaget’s world, offers opportunities to examine these levels of abstraction.

> **Analogies, or correlates in Spearman’s sense, are a sort of qualitative proportion. They are relations among relations, but without equality of cross-products. An example would be: feathers are to birds as fur is to land-dwelling mammals. (Piaget, 2001)**

He begins his explanation of levels with the concrete—empirical abstraction—and moves to a higher order state.

> **But because feathers are an objective characteristic of sparrows, just as fur is an objective characteristic of dogs, it is clear that the construction of an analogy must begin with empirical abstraction. In other words, it must aim at grasping properties that the subject did not introduce into the objects; rather, the properties existed in the objects before the sought after comparisons were undertaken. By contrast, when a correlation gives rise to quantifications and leads to its principal derivative, a proportion (such as 2 is to 4 as 3 is to 6), now we are dealing only with subject’s constructions. Hence have entered a domain in which reflecting abstraction operates. (Piaget, 2001)**

In a knots-like, R. D. Laing sense, Piaget's model for reflecting abstraction becomes observing concrete qualities, thinking, thinking about thinking (metacognition), and thinking about thinking about thinking (beyond the limits of metacognition).

Piaget's model provides a theoretical explanation of understanding as well--one useful for assessing children's mathematical understanding beyond most psychometric tests, exceeding the limits, for example, of many multiple choice tests, and reaching the realm of the creative and sublime.

As defined in the *Oxford College Dictionary*, analogy is "a comparison between two things, typically on the basis of their structure and for the purpose of explanation or clarification."

So said, when children can compare two otherwise unlike objects or ideas based on their less obvious structure to explain or clarify, they deepen their understanding. That is what Robert Marzano found in a meta-analysis of similarities and differences as a strategy for improving student achievement. That is what happens when children come to understand algebraic equations.

That is what happens when children engage algebra and analogies for kids as a thematic project in a performing arts magnet school.

They explain and clarify.

Deepening understanding may relate to Ellen J. Langer's work on Mindfulness theory at Harvard University.

A social psychologist who created a theory of intelligence that takes its place among a family of teachable intelligence theories (Fluellen, 2006), Langer says “a mindful approach to any activity has three characteristics: the creation of new categories; openness to new information; and an implicit awareness of more than one perspective.” (Langer 1989; 1997)

In contrast, Langer says “mindlessness…is characterized by an entrapment in old categories; by automatic behavior that precludes attending to new signals, and by action that operates from a single perspective.” (Langer 1989; 1997)

It may be that analogical thinking serves as an agent for mindfulness when explaining or clarifying.

But the teacher inquiry at hand speaks to research on analogical thinking in children. The literature offers relevant studies about analogical thinking in at least two categories:

- research on how children develop analogical thinking
- research on how to develop analogical thinking in children

Both categories heighten insights about “Algebra and Analogies for Kids.”

A handful of studies, including one presented at a meeting of the American Educational Research Association and Marzano’s explanation of how to teach analogical thinking within the context of his “similarities and differences” research based strategy for improving student achievement, speak to both sides of the analogy coin.

They reflect on the development of analogical thinking as well as how to teach children to thinking analogically. The literature adds value to Piaget’s view of reflecting abstraction and analogical reasoning of children in mathematics.

How children develop analogical thinking

In particular, English (1993) explored analogical thinking as the core of mathematical understanding of children. This study set out to “examine analogy as a general model of reasoning and to highlight its role in children’s learning of mathematics.” (English, 1993)

At the core, this study reviews research about the nature of analogical thinking and draws on Gentner’s definition of analogy and insights.

According to English, Polya’s 1954 definition of analogy laid a foundation for using Gentner’s more updated one. Polya had created a landmark descriptive study of analogy in which he defined analogous systems as ones agreeing in “clearly definable relations of their respective parts.”

Polya’s definition seizes the essentials but does not explain what those definable relations might be.

In contrast, Gentner defined an analogy as “a mapping from one structure, the base or source, to another structure, the target.” (English, 1993)

So defined, an analogy such as Piaget’s feathers is to birds as fur is to mammals illustrates a movement from base to target, one structure to another structure.

Adds Gentner, “normally the source is the part that is already known, whereas the target is the part that has to be inferred or discovered.”

For example, dog is to pup as cow is to calf. The dog is to pup draws on “parent of” as the shared relation between the known or base and the unknown or target. Other elements such barks are not mapped from dog to cow.

The insight English offers is that analogical reasoning “shares common features with knowledge-based models of reasoning.” (English, 1993)

Citing Halford (1992), English asserts that analogies “go beyond the information retrieved because the interaction of the base and the target produces a new structure that extends beyond the previous experience.”

Additionally, “employing an analogy can open up new perspectives for both perceiving and restructuring the analog.”

English says such a view of analogy squares with constructivist views of learning. In brief, learning is “an active construction process that is only possible on the basis of previously acquired knowledge.”

Learning deals with connecting new and existing ideas. (English, 1993)

"What is the difference between fractions and decimals?"

Mallard posed that question during the reflection period on a lesson about adding and subtracting fractions. Regularly, after the math specialist teaches a lesson, the teacher researcher had been engaging students in a reflection period. Systematic reflection allowed for intense mini lessons to clear up immediate misconceptions and confirm accurate conceptions. Occasionally, a student inquiry prompted further discovery beyond the 10 minute reflection period.

Fifth graders chose from three reflection questions at the end of the lesson:

- What squared with your thinking?
- What is still rolling around in your head?
- What more do you still want to know or understand?

As a student in a fifth grade class, Mallard wanted to know about the difference between these two mathematical ideas. That led the teacher researcher to challenge the class, asking them to explain similarities and differences between a fraction and a decimal in a Venn diagram.

Also, Mallard's question served as a segue into the algebra and analogies for kids project set to begin one week later—one in which students would encounter the Algebra unit in Houghton Mifflin's new mathematics program and regularly gain practice with creating analogies.

For example, the “Farmer Joe problem” became the entry point for the first workshop in “Algebra and Analogies for Kids,” a final fifth grade project. The task was to solve an unknown in a story problem:

Farmer Joe needed to get his fox, hen, and corn across the river safely. He could carry them only one at a time. How does he get each animal across safely?

A basic idea in the Houghton Mifflin algebra unit for fifth grade is to “use what you know” to find the unknown. Students knew the fox would eat the hen if they were left alone; the hen would eat the corn if given a chance. Algebra can deal with one single solution on the one hand, and novel or even multiple solutions on the other, particularly since the stuff of algebra is variables and often ill-structured problems.

Farmer Joe’s problem presents both classic and novel solutions.

Nyga said, “the farmer can take the hen over the river first. If he left the fox and corn, it would be safe. The fox won’t eat the corn.

The rest of her solution didn’t work, but she did get the first step in the classic response.

During the reflection period, the teacher researcher challenged students to complete the class solution by using nonlinguistic representations such as a river drawn on a blackboard as well as symbolic representations such as f for fox, h for hen, c for corn.

Then, the classic solution became the following: take the hen over first. Come back for the corn. Take the hen back and bring the fox, leaving the fox and corn on the final side of the river. Go back to get the hen.

Next, the class listened to two novel solutions, one of which made sense.

Hassan said, "build a cage for the fox and one for the chicken. Put the corn in a bag. Take them across the river one at a time."

Both the classic and the novel solutions deal with finding unknowns in a well-structured problem, but the novel solution goes beyond the deductive reasoning in the classic solution. It makes an analogical leap: safety equals cages for the fox and hen.

On the research side, when mining the literature on analogical reasoning, <u>how teachers might develop analogical thinking</u> in children emerged as a second theme.

Piaget suggested that children came to a deeper understanding as they constructed meaning along the lines of reflecting abstraction. (Piaget, 2001)

Such would be the case in the Farmer Joe problem. The classic solution requires more than **empirical abstraction**; the solution is not evident in the qualities of the fox, hen, and corn but in their relationships. Thus, it requires **reflecting abstraction**.

Likewise, the novel solution requires **reflected abstraction**. It elevates thinking about the baseline relationships between the fox, hen, and corn to the idea of <u>self containment increasing safety</u>.

No student in the first workshop achieved **metareflection** on the “Farmer Joe Problem.” No one, for instance, saw how the Farmer Joe problem was analogous to the Farmer Joe’s lily pod problem.

Students had engaged this problem a few months back in a multiplication unit: **After work, Farmer Joe goes fishing every day to relax. One day he saw a lily pod on the pond. The next day two lily pods were on the pond. The next day four pods—by the 28th day, half the pond was covered with pods. On what day would the entire pond be covered with lily pods?**

Not only did students fail to connect the two farmer Joe problems, no one thought about the connections between the problems and algebra or life.

Thus, no student took reflected abstraction to an even higher level, namely, metareflection.

While Piaget provided a theoretical explanation with implications for teaching children to reason analogically, it was Marzano who provided a specific approach. The teacher of mathematics could use his systematic, step by step mode as a research based strategy that might lead to increased higher order mathematical knowledge of children, namely analogical reasoning. (Marzano et al, 2004)

Additionally, it was Gardner who offered the MI approach featuring analogical thinking in his method, one based on multiple intelligences theory and a performance view of understanding. (Reigeluth, 1999; Gardner, 1999a; Gardner 1999b)

On the first day of the pilot Algebra and Analogies for Kids project, students received a storyboard (an instructional design in plain English laid out on a single, word processed sheet). The storyboard presented an entry point, **powerful analogy**, and multiple representations. Over a three day set, a one hour workshop per day, they engaged each of the three parts of Gardner's new paradigm instructional design.

As an "experiential" entry point, the Farmer Joe problem took the first hour of instruction. That was Monday, two days before the first day of spring in Savannah 2007. Trees around the campus of the school already had full green leaves. Winter coats needed in the morning. Bermuda shorts by afternoon.

Most of the hour inside the windowless classroom that opened to a breezeway and courtyard focused on understanding and solving the problem.

On Tuesday, students opened with a Korean Tai Chi form they had been practicing for 8 months. The teacher researcher used the form this morning to introduce two of the three algebra concepts in the project: equations and integers. Coordinate graphing would come much later in the project if time permitted.

So Tai Chi served as a bodily kinesthetic activity, a second entry point in Gardner's MI approach for teaching well. More importantly, it set up the powerful analogy.

Most of the Tuesday workshop time developed the powerful analogy embedded in Richard Wilber's poem "Mind."

"Mind in its purest play is like some bat that beats about in caverns all alone…"

After a dramatic reading and echo poem game, students wrote explanations of the following analogy at the core of Wilber's poem: **mind is to bat as knowledge is to cave.**

Eight thinkers shared their explanations with the class, then, the teacher researcher closed by inviting four students to answer the three reflection questions Dr. Copeland, a Georgia Department of Education Director, had offered in a workshop on collaboration.

It would be on the first day of spring that students would engage a few of the <u>multiple representations</u>:

- **survey of Houghton Mifflin's unit 8—algebra--chapter one using Harvard University Project Zero thinking routines to explore three algebra concepts, namely equation, integers, and coordinate graphing**
- **reading in mathematics (including math language such as equation, function, and function table as well as the language of thinking (vocabulary such as analogy and comparison)**
- **algebraic problem form (words, words and symbols, and symbols**
- **playing around with creating algebraic word problem forms in words and symbols as well as symbols**

So put, Gardner's new paradigm instructional design theory (teaching method) organized thinking into three parts:

1. entry point
2. powerful analogy or metaphor
3. multiple representations for deeper understanding

Each part uses an activity based on one or more of his nine intelligences, but never more than a handful.

Take, for example, a workshop in the pilot project for algebra and analogies.

The hour opened with the Tai Chi embodiment of equation and integer (a bodily kinesthetic activity). Then, it focused on “Reading and Math” from the Houghton Mifflin unit. That included the language of algebra—six key terms such as equation and function—as well as a look at problems presented in words, words and symbols, and symbols (a verbal linguistic activity).

Those served as double entry points.

Next, students worked in pairs to transfer their understanding of problem forms (interpersonal, intrapersonal, and logical mathematical intelligences). This was a powerful analogy: representing math problems in words, words and symbols or symbols with partners. Such transfer demanded analogical reasoning from model problems to original problems using words, words and symbols or all symbols.

Finally, they published their responses on chart paper and led whole class discussions with teacher commentary. Then, they engaged the three standing reflection questions (What squares with your thinking? What is still rolling around in your head? What do you still want to know or understand?).

Making their thinking visible involved multiple representations based primarily on activities set in Gardner’s interpersonal, logical mathematical and verbal linguistic intelligences.

Gardner's MI approach, a "new paradigm instructional design theory," continued to organize thinking for each workshop in the weeks ahead as the pilot study unfolded.

Along with Marzano's research based strategies, it assures that students will <u>think to learn</u> as they engage algebra and analogies in the study next school year.

Again, the teacher inquiry will be as follows:

What happens when kids display analogical thinking in an algebra project?

Methodology

For the actual study, the teacher researcher will collect observations of recitations, documents, performances, and portfolios emphasizing five student participants engaged in a 2007-2008, thematic project: "Algebra and Analogies for Kids." Summative and formative assessments that the five participants encounter and collect in portfolios will provide opportunities for analogical reasoning as refined with the Piagetian levels of abstraction. In addition, the five students, in isolation from the class, will engage replicated Piagetian tasks from ones he did in his original study of children's analogical thinking and the reflecting abstraction model.

All students will engage the step by step framework that Marzano et al provide to scaffold student use of analogies. Thus, for comparison, classification, metaphor, and analogy, they will follow the same steps for deeper understanding:

- **Use a model**
- **Use a familiar example**
- **Use a graphic organizer**
- **Use teacher guidance and transfer of understanding**
- **Use a rubric and reflection**

For example, after systematically working on comparison, classification, metaphor, and analogy the pilot group took on a workshop for algebraic expressions and equations in the McGraw Hill unit on Algebra for 5th grade.

Using counters or blocks as analogies for integers, students engaged a think-pair-share cooperative learning activity to work on a model problem in depth.

First, they applied the Read, Plan, Solve, and Look Back problem solving model to think about the model story problem: how many trees did the adults and youth plant? The story problem said five adults planted one tree each and eight youth planted one tree each.

To make the analogical connection, pairs of students spaced around the classroom with sets of colored tiles or blocks or pattern blocks to make a column of five with each object representing one tree. To find the unknown total, they added a row, one block at a time to represent the eight trees planted by youth and another column to represent the five trees. They, then, had to explain why the best answer was 13 trees and write an equation using symbols (letters and numbers) to summarize the problem.

Nyga, for example, said $P = 5a + 8y$

Finally, they used the reflection questions to extend their understanding:

- What squares with your thinking?
- What is still rolling around in your head?
- What do you still want to know or understand?

In a follow up activity, the children had to create a word problem from a print of a Jacob Lawrence painting or one of their own choosing. Then, he or she had to draw a picture of an equation using circles or some other shape, each shape standing for an integer. Finally, he or she had to invent an equation to summarize the word problem. A bonus problem was to explain the analogy:

Counter is to integer as symbol is to variable.

Such assessments during the “Algebra and Analogies for Kids” project next year--strategically timed to capture moments when the students seem well prepared--will become data about the five participant’s analogical thinking--in addition to the replicated Piagetian tasks.

There may be as many as three to four of these strategic, teacher-made, performance based assessments. Also, during the two month data collection period, a set of replicated Piagetian tasks will be scheduled during the lunch times of the target participants.

These Piagetian sessions may be video tapped to provide an additional level of analyses with Piaget’s reflecting abstraction model as an observation rubric to examine empirical abstraction, reflecting abstraction, reflected abstraction, and metareflection.

Within the context of the “Algebra and Analogies for Kids” project, the data collection period for the teacher inquiry will be from September to October 2007.

The data collection period will feature Marzano’s step by step process for similarities and differences as well as Howard Gardner’s MI approach to deeper understanding. (Reigeluth, 1999; Gardner, 1999a; Gardner, 1999b; Marzano, 2004)

Thus, students will experience algebra across selected intelligences in Gardner’s multiple intelligences theory in every workshop while they engage Marzano’s specific steps in the “multiple representations” phase of Gardner’s MI approach. And, always, they will focus on a performance view of understanding—one making thinking visible.

Note that a performance view of understanding demands active learning including a fair amount of reflection, recalling David Perkins’ assertion that “reflective intelligence” augments “experiential intelligence” and “native intelligence. Reflection makes kids smarter. (Blythe, 1999; Wiske, 1999; Perkins, 1995)

Additionally, Robert Sternberg’s work on *Thinking Classrooms* will inform the basic shape of the “Algebra and Analogies for Kids” project. (Sternberg and Spear-Swerling, 1996)

Drawing from his triarchic theory of intelligence, Sternberg’s framework assures that instruction with the MI approach and the embedded Marzano research based strategy for “similarities and differences will balance teacher centered, fact based questioning, and student centered approaches with an emphasis on the more interactive student centered approaches. (Sternberg and Spear-Swerling, 1996; Fluellen, 2006c)

Non random selection of students will be appropriate for such a small sample size of five. Also, the ethnographic nature of the inquiry permits non randomization. Thus, five selected students representing a cross section of logical mathematical intelligence with back up students to account for mortality (students who transfer out) will comprise the sample. The data analysis period will be from November to December 2007.

Finally, the data results will be ready for publication in January 2008 to February 2008. The resulting paper may become available for readers of the Education Resource Information Center (ERIC) world wide data base sometime later in 2008.

Also, the teacher researcher may present the paper as “practitioner research” at the International Research Forum at University of Pennsylvania, February 2008 or a future meeting of the American Educational Research Association (AERA).

Finally, the teacher inquiry itself serves as one of four interacting factors of educational reform in Fluellen’s *power teaching prototype* now ending its first year of development at an urban public school in the South. (Fluellen, 2006d; 2007a, 2007b, 2007c, 2007d)

In summary, the inquiry follows the timeline below.

<u>Data Collection</u> **What happens when kids display analogical thinking in an algebra project?**	**September to October 2007**	**6 weeks:** **algebra and analogies workshops** **With Gardner's MI approach as method; Marzano's research based strategy for similarities and differences embedded in the MI approach as multiple representations; and Sternberg's research based thinking classroom as the deep level structure**	**Collecting data from field notes of observations plus documents, performances, and portfolios of five students; looking for evidence (or lack of evidence) of analogical thinking; includes replicated Piagetian tasks for analogical thinking in mathematics and his reflecting abstraction model**
<u>Data Analysis</u>	**November to December 2007**	**6 weeks: Student authored intellectual products in algebra**	**Assessed with Marzano's rubric for analogies; Piaget's reflecting abstraction model to describe levels of understanding**
<u>Data Results</u>	**January to February 2008**	**6 weeks: writing an ethnographic story of analogical thinking**	**Story of what happens when kids display analogical reasoning**
Outcomes **March to June 2008**	**Publication in the occasional paper** series	**Presentation at a professional conference research**	**Preparation for more extensive research on analogical reasoning**

Conclusion

While a lot is known about analogical thinking in children, little is known about Piaget’s reflecting abstraction studies of analogical reasoning beyond his Center for Genetic Epistemology. “Algebra and Analogies for Kids” will yield insights about how five children, in particular, engage analogical thinking through the lenses of Piaget’s reflecting abstraction studies. New inquiries about analogical reasoning in mathematics will emerge.

In addition, the instructional side of the project will present a systematic approach for developing analogical thinking in children—one based on the combination of Gardner’s new paradigm instructional design theory—the MI approach—and Marzano’s “similarities and differences” research based strategy for improving student achievement. Theory weds practice.

The kids will engage higher order knowledge in algebra and the teacher researcher will create higher order knowledge as an ethnographic story.

Finally, the “Algebra and Analogies for Kids” project will most certainly embody the words of Peter Senge: “All learning integrates thinking and doing.”

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About the author

Born in Atlanta, Georgia and educated at Cheyney University, Temple University, University of Pennsylvania, Harvard University, and Howard University, Jerry Fluellen doubles as a grade teacher and educational psychologist. He has served as a university instructor, research center coordinator, teacher consultant, grade school teacher, editor, and writer.

The Education Resource Information Center has published 24 of his documents including a book on multiple intelligences, two curriculum maps, and several book length papers such as “The Titmouse Effect (Power Teaching in 2054).”