Active Learning in Middle School Mathematics

Introduction

Active learning is fundamental to meeting the needs of early adolescents. The National Council of Teachers of Mathematics (NCTM) has long promoted pedagogical methods that require students to be intellectually engaged in constructing new knowledge with conceptual understanding (NCTM, 2000; NCTM, 2014). Instructional strategies centered on active learning include problem-solving tasks, questioning, and inquiry. Additionally, social and physical activities are also important instructional strategies included in this field.

The purpose of this article is to discuss a framework for thinking about active learning in middle-grade mathematics classrooms (see Figure 1). Middle grades students respond well to active learning, but there are different ways of thinking about activity in the classroom. Instructional strategies that require students to be intellectually active should certainly be at the heart of any mathematics lesson; however, early adolescents need other types of active learning strategies as well, and mathematical problem solving promotes this activity. A Venn diagram was purposefully selected to represent the active learning framework. There are several instructional methods that simultaneously address multiple categories of intellectual, social, or physical activity.

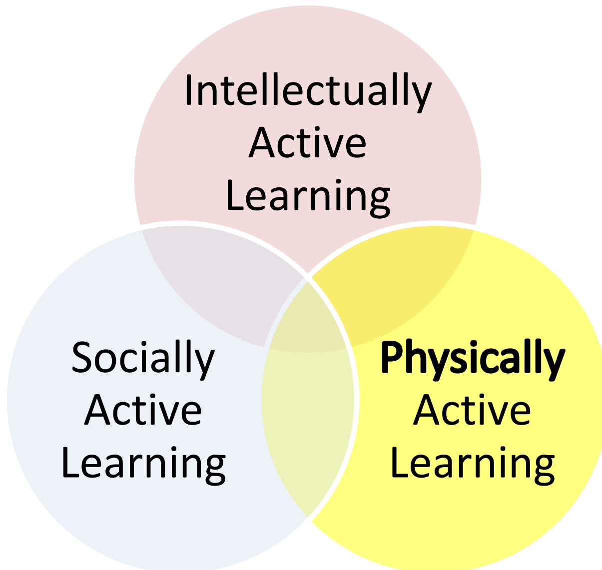


Figure 1: Active Learning Framework

Intellectually Active

Students must actively engage in learning and construct their own understanding. A deep conceptual understanding of the mathematics involves knowing and understanding the underlying principles of the concepts, not just memorizing rules, definitions, and procedures. Learning with understanding involves developing relationships among mathematical concepts and enables students to extend and apply their mathematical knowledge to new and unfamiliar problems. Students have ownership over the mathematical knowledge and are actively involved in constructing new knowledge. Teachers serve as guides as their students develop mathematical ideas and come to experience the power of mathematical thinking for themselves. This idea is supported by NCTM's (2000) learning principle, "Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge" (p. 20).

An important theme in the literature related to mathematical problem-solving is the cognitive demand that a task requires of students. Stein, Smith, Henningsen, & Silver (2009) offer a framework for looking at the cognitive demands of tasks. Low-cognitive-demand tasks require that students demonstrate memorized knowledge or perform procedures without connections to any context. High-cognitive-demand tasks require higher levels of cognitive demand and mathematical reasoning. Students need to attach meaning to the mathematics they are learning and make connections among different mathematical representations. In order for students to be intellectually active in their learning, it is important for teachers to select problem-solving tasks that require higher levels of cognitive demand.

An example of instructional strategies requiring students to be intellectually active comes in the form of high-level problem-solving tasks. When students are asked to solve unknown mathematical problems rather than to simply memorize repeated procedures, they are actively engaged at a higher intellectual level. Students are further required to be intellectually active if they are asked to explain their reasoning for solving the problem and asked to justify their mathematical thinking (Mueller & Maher, 2009). Concept maps are another instructional strategy necessitating students to be intellectually active as they consider connections among different mathematical concepts (Afamasaga-Fuata'i, 2008).

Socially Active

Another critical part of the learning process for mathematics students in middle grades involves mathematical discourse (Piccolo, Harbaugh, Carter, Capraro, & Capraro 2008). Mathematical discourse is the method of engaging students in socially active learning. We have seen a change in mathematics classrooms over the last 25 years from students individually computing problems in their neatly lined rows of desks to students working in a collaborative community where they fluidly share ideas and solve problems together. Current best practices in mathematics instruction emphasize social interaction within the classroom (NCTM, 2014). Teachers encourage students to collaborate in order to they share and develop mathematical meaning. Teachers also build a sense of community where students feel safe to take risks and express their thinking by promoting intra-classroom interactions that foster community problem-solving and reasoning. One model of active learning occurs when students are engaged in contextual problems and teachers serve as facilitators and guides. Students then struggle through concepts and initially explain, delineate, and finally justify their reasoning to their peers while learning from their classmate's ideas. Through communicating their reasoning to each other, students are able to clarify mathematical ideas for themselves. Within the classroom discourse dynamic, the teacher poses questions, listens carefully to the ideas of students, and encourages students to participate in productive mathematical discourse. Through this process, students negotiate mathematics and form shared meanings of mathematical concepts (NCTM, 2000).

Collaborative learning is particularly effective with young adolescents since they are extremely peer-oriented. Developmentally, middle school students are becoming more concerned about the thoughts and ideas of their peers and they characteristically long for social acceptance (Brighton, 2007). Socially active instructional strategies can include whole-class discussions, small-group discussions, small-group problem-solving, and small-group projects.

Physically Active

Young adolescents need to be physically active in the classroom for several physiological reasons. One reason is that their endocrine systems are finishing development and still stabilizing. It is not uncommon for the adrenal glands of a young adolescent to produce a surge of adrenalin (Brighton, 2007). This creates an urge to move, which is, fortunately, *not* problematic if the student is already engaged in an activity allowing for movement (as opposed to a more sedentary endeavor such as sitting still in a desk completing a worksheet). An additional reason that young adolescents become restless is because during this developmental period, their last three vertebrae fuse together to form their tailbones (Brighton, 2007). This discomfort can be minimized if students are allowed to move while completing learning activities. Of course, middle school students need not move every minute of every class period, but incorporating some meaningful physical activity into lessons is important.

Fortunately, hands-on instruction, including manipulatives, has long been recommended in teaching mathematics. In their meta-analysis of 55 related research studies, Carbonneau, Marley, and Selig (2013) reported that using manipulatives can produce a positive effect on student learning. Hands-on instruction can be particularly helpful for early adolescents who find themselves moving from Piaget's concrete operational stage to the formal operational stage (Piaget, 1972). Developmentally, early adolescents are increasingly able to handle abstract concepts, but hands-on activities can help develop this mathematical understanding. Having students work with multiple representations (concrete, visual, and abstract/symbolic) of the same mathematical concept simultaneously can assist their move from concrete thinking to abstract thinking.

Classroom Examples of the Active Learning Framework

Provided below are several classroom examples along with their designation of where they intersect with the active learning framework. These three examples fall within the overlap of two or more of the framework's dimensions, but it is also possible for an activity to fit into just one dimension. For example, if students are asked to individually create a concept map of a mathematical concept, this would fall only within the Intellectually Active dimension. It is also important to note that the instructional activities selected for a lesson should not only involve active learning, but should be purposeful as well (Association for Middle Level Education, 2012). This framework can be applied in a real middle school mathematics classroom. Consider the following classroom examples of instructional activities as illustrations of the active learning framework:

Integers Number Line. The number line is an excellent representation for computation with integers. Using masking tape, the teacher creates a giant number line on the floor of the classroom. The teacher then allows students to physically walk through integer computation problems on this line. As the student walks through a problem such as 3 + -5 = -2, the teacher asks the student critical questions such as, "Why is the answer negative two instead of positive two?" or "How can we determine what the sign of the answer will be?"

Since the students are making observations and generalizations about adding integers, this instructional method would fall under that dimension of Intellectual Activity. Students are also physically active as they move along the floor-based number line, a sharp contrast to them sitting and completing problems on a worksheet-based number line with pencil and paper. Therefore, this activity would fall within the intersection of the Physically Active and Intellectually Active dimensions on the active learning framework (see Figure 2).

Scientific Notation Activity. Students are given several examples of numbers that are written side-by-side in standard notation and scientific notation. The students are then asked to work with a partner to determine what shortcut the scientists used to write the numbers in scientific notation form. After students are given time to work in small groups on the task, the teacher brings the class together and engages the students in a whole-class discussion where generalizations are made and rules are established for translating numbers between the two forms.

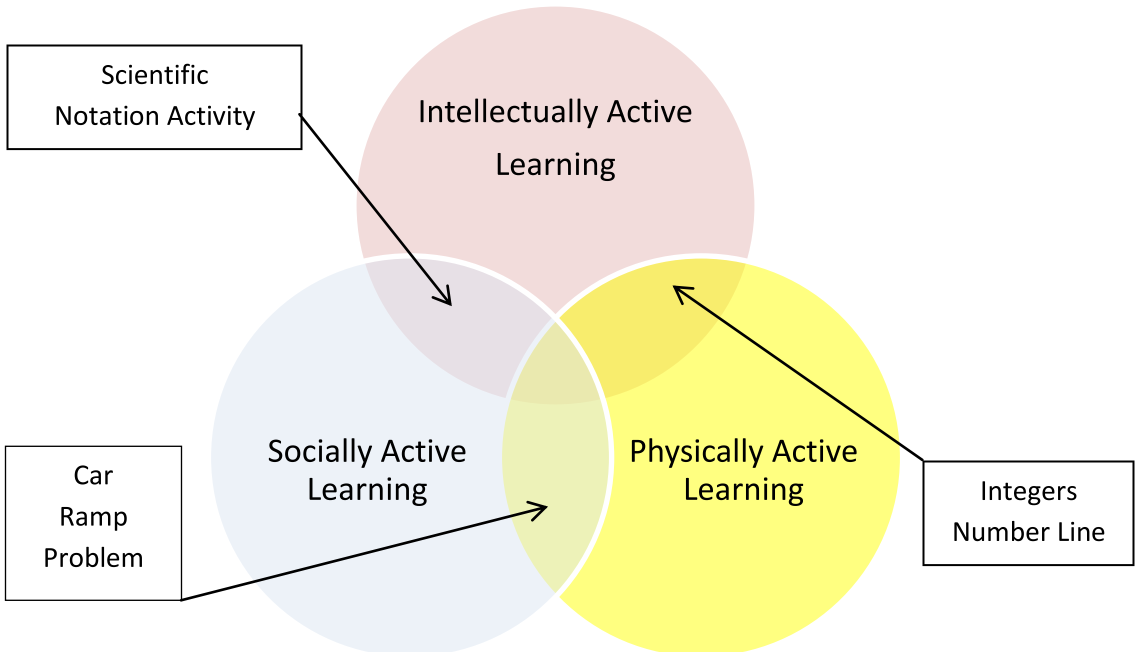
Since this activity has the students engaged in an inquiry method of making generalizations and forming their own rules, it would fall under the dimension of Intellectually Active learning.

But since the students are working in both small groups and within the larger classroom community to determine these rules, it would also be considered Social Active learning. Therefore, this activity would lie within the intersection of the Intellectually and Socially Active dimensions (see Figure 2).

Car Ramp Problem. Students create ramps out of strips of thick cardboard and stacks of books and roll toy cars down the ramps, measuring how far each car rolls. The height of the ramp is adjusted by adding or taking away books and several trials are measured at each height. After collecting the data, the students graph the average length of the roll in relation to the height of the ramp and determine a line of best fit in order to make predictions about how far the car will roll at other heights.

The car ramp problem actually falls within the intersection of all three dimensions of active learning (see Figure 2). The students are Intellectually Active when they solve a complex problem that makes connections between several different mathematical concepts and has them applying those concepts to a novel situation. The students are Socially Active as they work within small groups and solving the problem together. Finally, they are Physically Active when they are on the floor doing the actual experiment with cars, books, ramps, and yardsticks.

Figure 2: Examples Aligned with the Active Learning Framework



An Active Learning Lesson Plan

Mrs. Miller's 8th grade class is focused on cylinders and spent yesterday deriving the formulas for surface area and volume of cylinders using nets. Today, she wants to reinforce finding the surface area and volume of a cylinder while beginning to solve related problems. Below is a summary of her lesson plan and how it relates to the active learning framework.

9:00-9:05: Mrs. Miller begins the lesson with an introductory review activity. She has the students stand and they toss a large beach ball that has relevant vocabulary words and formulas written randomly on the ball's surface. When a student catches the ball, that student is required to explain what she or he knows about the concept lying closest to her or his right index finger. Mrs. Miller then asks follow-up questions that help to make connections between the terms. *(Physically Active Learning)*

9:05-9:10: Mrs. Miller reviews the formulas for surface area and volume of cylinders and presents a problem on the board requiring the students to use these two formulas to determine this information for a given cylinder by looking at the two-dimensional visual representation on the board.

9:10-9:40: Placed in groups of four, the students are given a soda can and a ruler and are asked to find the surface area and volume of the soda can. Once they are confident that each member of their group can explain the process, they call Mrs. Miller over and she proceeds to question the students. If she is convinced that every student in the group can find the surface area and volume of the soda can accurately, she gives each group member their own soda to drink while they complete the next part of the activity. This next part asks students what would happen to the surface area and volume of the can if the height were doubled. The students also must determine what size the new label of the can would need to be, and they discuss whether or not the manufacturer should change the size, ultimately giving a rationale for their conclusion. *(Intellectually and Socially Active Learning)*

9:40-9:55: Mrs. Miller leads a class discussion about the problem. She asks different groups to present their solutions and justify their reasoning. *(Intellectually and Socially ActiveLearning)*

9:55-10:00: Mrs. Miller assigns several textbook problems for homework and gives the students time to clean up the materials used during the activity. The students are asked to find the surface area and volume of a given cylinder on an "exit slip" which they give to Mrs. Miller upon leaving the classroom.

Throughout this lesson, Mrs. Miller had her students engaged in active learning. While not every activity required active learning, the majority of the class time was spent doing Intellectually, Socially, and/or Physically active learning.

Conclusion

Active learning has been recognized for some time as critical to the mathematics instruction of early adolescents (Nesin, 2012). Middle grades students need to be actively engaged in learning rather than simply existing as passive recipients of mathematical knowledge. Active learning should engage students intellectually, socially, and physically. Mathematical tasks that engage students in as many types of active learning as possible are desirable and will engage students, as long as the tasks selected require students to be engaged in purposeful, active learning.

It is important for mathematics educators to support teachers who are endeavoring to implement active learning approaches in their classrooms. Currently many teachers assert that it is difficult to keep students intellectually, socially, and physically active in the classroom due to pressures resulting from the current emphasis on standardized testing. Research is needed to understand how to help teachers effectively implement these instructional strategies.

The world is changing and the marketplace is changing. Employers consistently say that they want to hire employees who have well developed skills in areas such as collaboration and critical thinking. It is not as important in today's society to have memorized endless pieces of information. We have technology that makes it convenient to retrieve factual information whenever necessary. Our students need to be able to think critically, to solve unknown problems, and to figure out things on their own. Active learning in the mathematics classroom is the best approach to get them there.

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