How the Montessori Upper Elementary and Adolescent Environment Naturally Integrates Science, Mathematics, Technology, and The Environment

by John McNamara

John McNamara shares his wisdom and humbly credits Camillo Grazzini, Jenny Höglund, and David Kahn for his growth in Montessori. Recognizing more than what he has learned from his mentors, he shares the lessons he has learned from his students themselves. Math, science, history, and language are so integrated in the curriculum that students comment they don't even think whether they are doing science or math. A schedule that allows time for students to follow a query to a conclusion is vital to the kinds of discoveries John's students make, such as a shortcut for multiplying binomials or reconfiguring cubing materials that made even John marvel at student independence and innovation.

Since much of what I am presenting here comes out of conversations with (and what I have learned from) my students, I want to begin with my background. This is my forty-fourth year at Ruffing Montessori School. I have been working with adolescents since 1976. I am presently teaching or have taught fifteen students whose parents I also taught. Four of the teachers at Ruffing were previous students of mine. Anna, in the musical *The King and I,* said, "if you become a teacher, by your pupils you'll be taught." This has certainly been true for me.

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I want to begin with two stories that have had a huge impact on my approach. This first event happened over thirty years ago. I had a young lady in my class who was constantly moving all over the classroom, disturbing the other students and driving me crazy. At the end of a particularly frustrating day I approached her and told her she should drink a lot of water before coming to school the next day. When she asked me why I told her that we were going to be attached at the hip and that the only time she was going to be free of me was when she had to go to the bathroom. The next day, being at my side and under my constant supervision, she accomplished more than she probably had in the previous month. I was so proud of her. At the end of the day I approached her to tell her how pleased I was. Luckily, before I had a chance to talk to her, I overheard her saying to her friends that this was the worst day of her life. Boy was I lucky to overhear her before I spoke.

As Ginni Sackett said yesterday morning, you can only offer experiences to children, you cannot impose experiences on children. You cannot individualize teaching, you can only individualize learning.

The second story also took place a number of years ago. At a parent discussion a couple of parents were complimenting me about all that their children were learning in my class. A father then interjected that before I get a swelled head I should remember that the only reason my students were doing what they were doing is because of what went before—in the elementary and primary. That is so true. Working with adolescents allows you to truly appreciate how students grow toward independence in a Montessori environment. This is best expressed by Jenny Höglund in an article on valorization. She writes:

> Valorization is beginning to become aware of one's capabilities, assets as well as weaknesses. This awareness comes from within and is not what someone else ascribes you. It is due to a growth through one's own work, a succession of achieving different levels of independence in correspondingly suitable environments. It is heading toward maturity and coordination of all one's potentialities. (162)

In *The Absorbent Mind,* Maria Montessori wrote, "And so we discovered that education is not something which the teacher does, but that it is a natural process which develops spontaneously in the human being. It is not acquired by listening to words, but in virtue of experiences in which the child acts on his environment. The teacher's task is not to talk, but to prepare and arrange a series of motives for cultural activity in a special environment made for the child" (8).

Camillo Grazzini wrote:

> In *Education and Peace*, Montessori talks about understanding ends and means. What we offer is a means, not an end. The disciplines are a means for development. To the three-to-six child we give keys to the world, to the elementary child keys to the universe, to the adolescent the keys to society. But how can you give the keys if you don't have the knowledge and don't know what's out there to explore? Loving the world is dependent on knowledge. The future of the method points to the kind of Montessori adults we need to teach our children. We need teachers that are grounded in knowledge, vision, and attitude all at the same time. You cannot be half Montessori. You cannot manage just the materials without vision and attitude. (23)

We have to constantly read and reread Maria Montessori's works so that we don't get caught up with what is urgent in place of what is important. I have been very lucky to have had three Montessori mentors (Camillo Grazzini, David Kahn, and Jenny Hoglund) who have helped me keep the vision and attitude.

Or, in the words of my students, school should not be a place where young people come to watch old people work. They also gave me a plaque that said the following: "Those that can do, those that can't teach, and those that can't teach, teach Montessori."

A statement that has influenced me is Mario Montessori's "Because man was endowed with imagination and knew to what use to put it. Did he, seeing a bird flapping his wings and flying from one tree to another, go up the tree, flap his arms—and break his neck? No! What he did was use his imagination not fantastically, but creatively, so as to bring out from the non-existence, something that would exist and might be of practical advantage to him" (*The Human Tendencies and Montessori Education* 20).

Ken Robinson, in his book, *Creative Schools*, defined creativity as "the process of having original ideas that have value." In the spirit of Mario Montessori and Camillo Grazzini, he wrote that imagination is the root of creativity. It is the ability to bring to mind things that aren't present to our senses.

I want to give two examples of this manifesting itself in my class. We were doing a lot of mental math multiplying binomials (figure 1). One morning two students became really engaged in multiplying binomials. They were getting really excited about what they were doing. After a while, they came up to me and told me that they had discovered a shortcut to square any number whose unit digit ends in 5. They had me square 35. In our mental math, from previous work with binomials, we would square as follows: (30 + 5)(30 + 5) = (30 * 30) + (5 * 30) + (30 * 5) + (5 * 5) =900 + 150 +150 +25 + 1225. They said that another (faster) way they discovered was to take the tens digit (in this case 3) and the next higher tens digit (in this case 4), multiply the two digits together (giving you 12) attach 25 and you have 1225.

They then squared 65—my way (60 + 5) (60 +5) = (60 * 60) + (60 * 5) + (5 * 60) + (5* 5) = 3600 + 300 + 300 + 25 = 4225. Their new way—6 * 7 = 42, then attach 25= 4225.

I then asked about three digit numbers. Let's square 105 your way and my way. My way (100 + 5)*(100 + 5) = (100 * 100) + (100 * 5) + (100 * 5) + (5 * 5) = 10000 + 500 + 500 + 25= 11025. Their new way—10 * 11 = 110, then attach 25 = 11025.

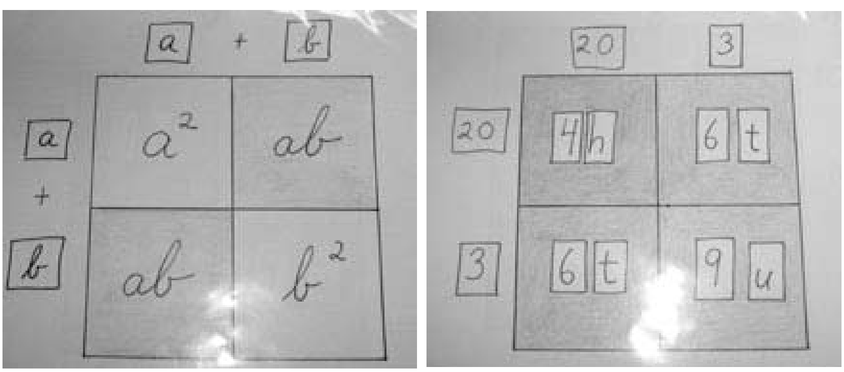

Figure 1. Multiplying binomials.

I was astounded. I had never known this shortcut. I then asked them why their method worked. They patiently explained to me both the reason it works and the reason I had never known this. They said that instead of squaring a binomial using only positive numbers (which I always do) that you could square 35 by making it (30 + 5) * (40 – 5) = (30 * 40) + (-5 * 30) +(40 * 5) + (-5 * 5) = 1200 – 150 + 200 – 25 = 1225. It always works out that you just have to attach 25 to the product of the tens digits. These two students could not have made this discovery without a solid grounding in Montessori math using materials. I might add that without long uninterrupted work times that allowed them to think, ponder, and even daydream I don't think they would necessarily have discovered this. It does not matter how many others know this shortcut. In their minds (and in mine, much to their satisfaction) they discovered something new.

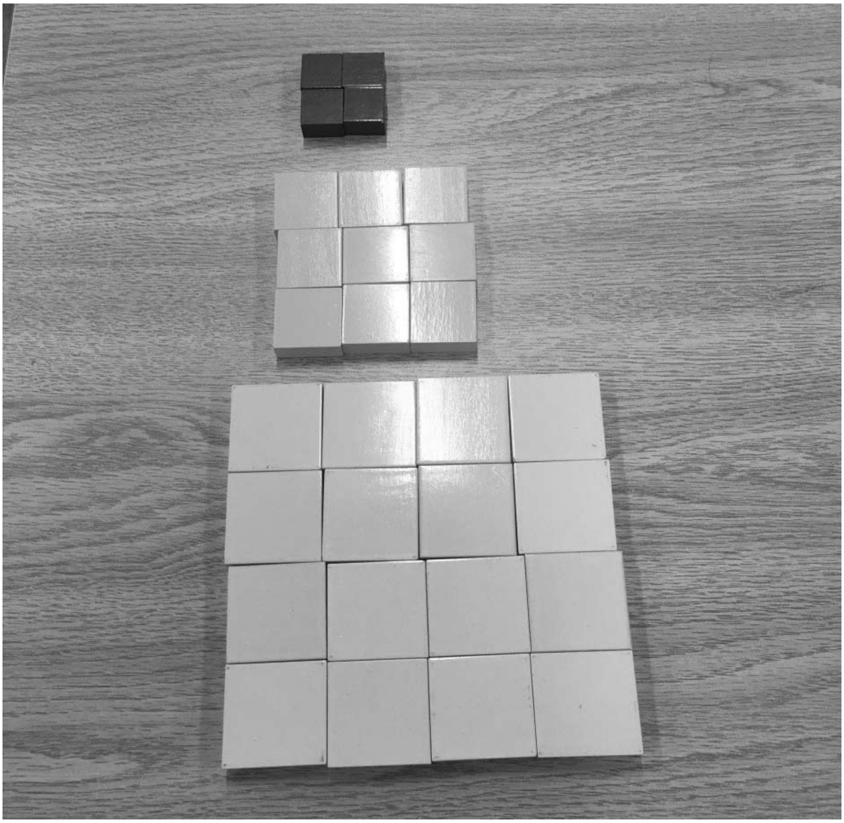

Figure 2. Student exploration using the cubing material.

I might also add that if these students were in the habit of using a calculator too frequently for computation they also may not have discovered this.

Around the same time I had other students exploring with the cubing material. They built squares (figure 2) and discovered relationships. They discovered that there was a relationship between the number of blocks on the side of a square and the number of blocks on the perimeter. They then made a table and a scatter plot and came up with the linear relationship y = 4x – 4 (figure 3). Having made this discovery, they continued exploring and discovered that there is a relationship between the number of blocks on the perimeter of the square and the number of blocks left. Again they made a table and a scatterplot (figure 4). These students had not yet been introduced to quadratic functions. Thus their discovery served as a good introduction to that topic.

This is a good example of the active role of the student. Beginning with an exploration of the cubing material, this group of students ended up covering a unit on quadratics with very little direction from me. The concluding activity arose out of a student realizing that the shape of their teeth formed a parabola and all the students coming up with quadratic equations for their teeth.

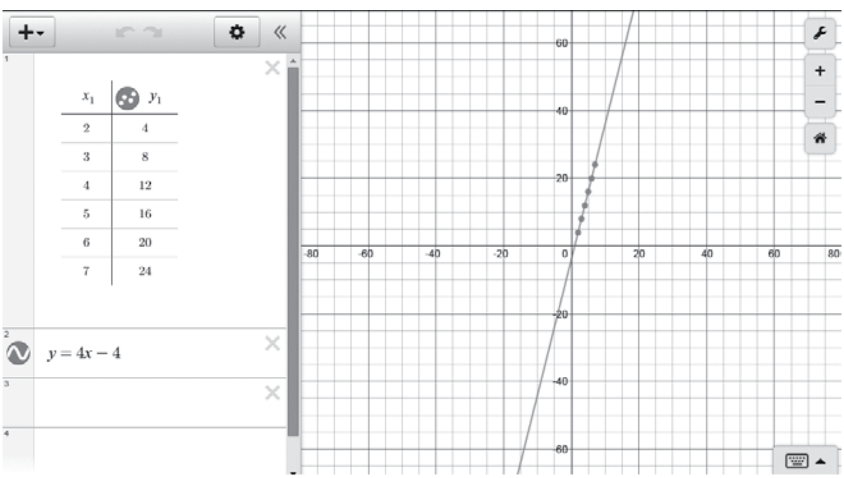

Figure 3. Student graph of the relationship between the side of a square and its perimeter.

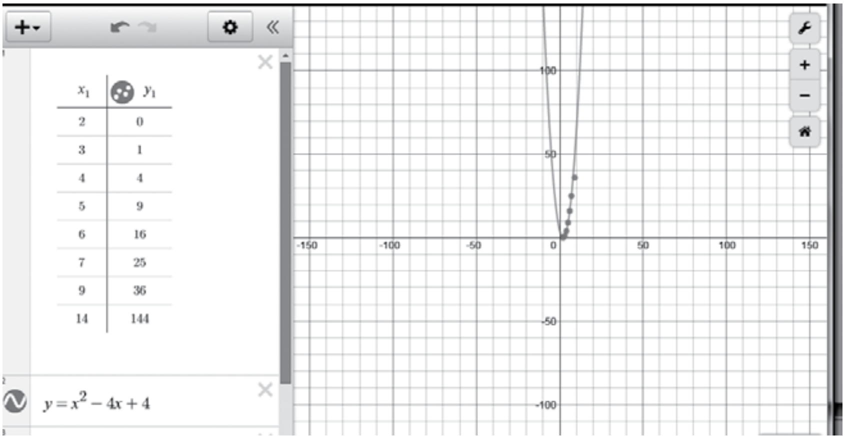

Figure 4. Student graph of the relationship between the perimeter of a square and the remaining blocks.

These activities reminded me of the Montessori idea that details by themselves bring confusion, that it is the relationships between things that lead to knowledge. As Camillo Grazzini wrote, “The question of what is relevant to the children, what engages the children and keeps them interested, must be asked…It is the philosophy behind subjects that makes for a cohesive Montessori statement, not facts by themselves” (17).

In Montessori environments, complex tasks are made not simple but, with application and effort, doable. Montessori’s principle of isolation of difficulty breaks complex tasks down into a series of simpler tasks so that problems do not become insurmountable obstacles. Students learn both that there are challenges to be met and challenges they can meet.

These math activities are also a reminder of four important aspects of the Montessori math material at all levels—formula derivation, exploration, and rules and formulas as a point of arrival and discovery, not a point of departure. Montessori materials are truly materials of development, not teaching aids.

Entrepreneur and author Peter Sims in his article “The Montessori Mafia,” published in the *Wall Street Journal*, asks:

> Is there something going on here? Is there something about the Montessori approach that nurtures creativity and

> inventiveness that we can all learn from? . . . Of course, Montessori methods go against the grain of traditional educational methods. We are given very little opportunity, for instance, to perform our own, original experiments, and there is also little or no margin for failure or mistakes. We are judged primarily on getting answers right. There is much less emphasis on developing our creative thinking abilities, our abilities to let our minds run imaginatively and to discover things on our own. But most highly creative achievers don't begin with brilliant ideas, they discover them.

Mario Montessori wrote, "…the tendency towards mathematical conception exists! Man used it in the past and he uses it nowadays in order to achieve whatever purpose he may have (22). Baiba Krumins Grazzini, in her talk yesterday, demonstrated how every branch of study is integrated, and that integration is there from the beginning.

Mathematics is central to this integration. A number of years ago, a parent asked me why the children made timelines of their short lives. As I pondered this question, I realized how important mathematics is to every branch of study and its integration. The cosmic view exposes the child's imagination to life at the beginning. However, to truly make contact with the origin of the universe, students need the concept of time. First, the child's own life marked by birthdays. Then the child's timeline in relation to that of the child's family. Then the family timeline to history timelines, units of time no longer birthdays but centuries. Then human time to geological time—time added to biology, geography; evolutions did not happen apart from dynamics of the Earth—thus biological time is geological time and fossils become the link between the living world of the past and the living world of the present. Mathematics is an integral part of this story. The concept of time, the concept of history, the concept of science become interwoven.

When I asked the students to give practical examples of how math, science, technology, and the environment are integrated in the prepared environment they gave a number of examples. They also pointed out that they don't stop and ask themselves whether they are doing math or science.

What started as a leaf scavenger hunt—finding and identifying leaves (e.g., oak, maple) evolved into a coordinate plane activity (figure 5). My role in the activity involved asking questions such as, “What would you have to do to move the leaf to different quadrants or up and down the y-axis?” to add a depth of understanding and awareness of what they had learned.

Another student mentioned how she had been using temperature probes to measure temperature on different parts of the globe—e.g., tropic of Cancer, equator—and decided to measure the hours of daylight and darkness in each of these locations for every day of the year. She later modified her measurements to sample every tenth day (figure 6).

The students said that most of the projects and activities they get involved in on their own revolve around themselves and their environment. Before I go further, I want to make a few cautionary comments about the use of technology. The activities that I mentioned previously and ones that I am going to mention later all involve technology to some degree. However, technology is never the direct aim. As previous examples hopefully illustrate, my aim is to have students use technology in ways that enhance learning,

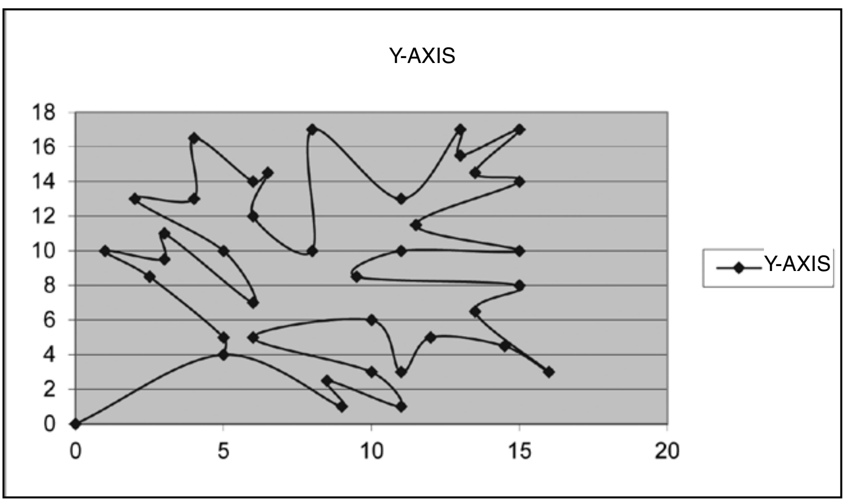

Figure 5. Student graph of a leaf.

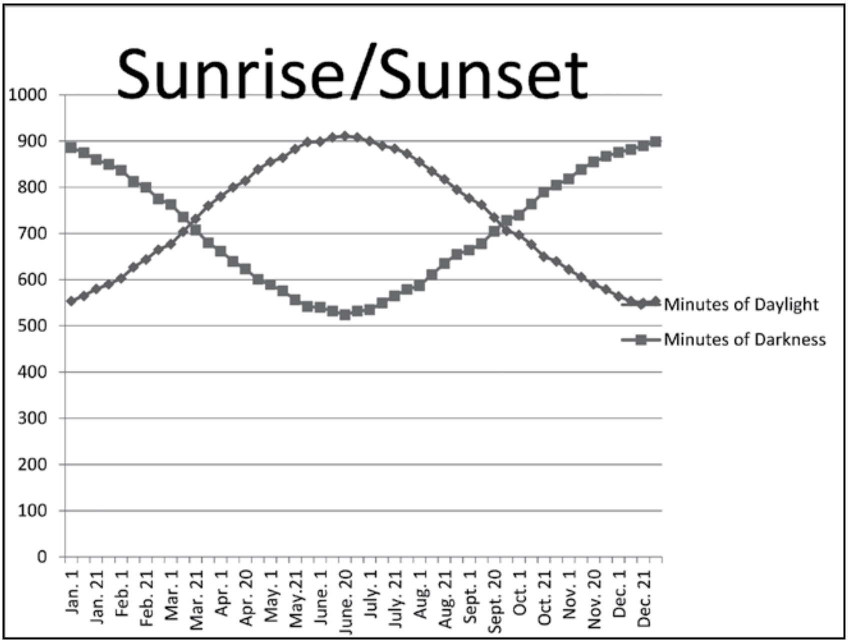

Figure 6. Student measurement of daylight hours.

not to replace the mathematical or science discovery. Unfortunately, I feel that sometimes, in an attempt to make technology relevant, the emphasis shifts to asking the question, "What can I do to use technology?" rather than, "Are there technologies that help students meet their objectives?" That is always my goal with technology.

Technology's ability to reduce the time and effort needed to perform tasks, both menial and highly complex, is a big source of its appeal. However, the main reason Montessori students perform many tasks is to develop themselves, not to finish the task. It is possible that, by reducing the amounts of time, effort, and energy needed to perform tasks, technology also threatens to diminish qualities such as self-discipline, sustained concentration, and in-depth deliberation—one of the most important aspects of Montessori; students will finish the work, not for the completion of the work, but for the sake of the work itself.

I have an expectation that all students "Be Galileo." The environment provides them the opportunity to do so. The environment presents students with opportunities to ask questions, make predictions about possible outcomes, and explore problems relevant to them as opposed to problems or experiments in textbooks or that I provide. Following are a few examples of projects that students have designed and carried out.

The first example involves the growth of sunflower seeds (figure 7). Several students observed (in all the times I was in the garden I did not) that the closer the sunflower plants were to the greenhouse the taller the plants were. Why this might be so puzzled the students and they wanted to know the reason. I had no idea. This led to a numbers of hypotheses and experiments to try to answer the question.

Students often use the garden as a backdrop to study the effects of nature on the body, on the effectiveness of studying and working in the garden versus working indoors. They not only attempt to measure academic retention and concentration but also things like blood pressure, heart rate, and body temperature. Some of the

Figure 7. A group of students studied the heights of the sunflowers in the garden.

Figure 8. Ruffing Montessori School, Rocky River, Ohio

questions they tested were as follows: Can I study better outside? Can I concentrate better? What effect does being outside have on my blood pressure, body temperature, and heart rate? Why? Are seminars more effective outdoors?

When the day is not scheduled and allows uninterrupted periods of time for thought, observation, and daydreaming, students end up asking many questions. Another example, in a discussion on skin cancer, students came up with and tried to answer the following questions: How effective are different sunscreens? What about different sunglasses? Do we really need sunscreen on cloudy days? How protective is our clothing—natural vs. synthetic, etc.? What about standing on the grass versus standing on the pavement? In attempting to answer these questions they are obviously doing science but also much mathematics, and technology (probe ware) makes answering these questions, in their minds, more scientific. They also bring these questions inside. For example, they design experiments to see how different activities (e.g., giving speeches) affect heart rate, temperature, blood pressure, and other measureable attributes. I might add that the students tape all of their presentations and evaluate them both at the time and by comparing the different presentations they give over time to evaluate how they improve.

Maria Montessori believed that a goal of education should not be to fill children with facts, but rather to cultivate their own natural desires to learn. In a Montessori environment, this objective is approached in two ways. First, by allowing each student to experience the excitement of learning, and second by helping all students perfect their natural tools for learning. Activities like the ones described above go much further to engage students than having scheduled science class, math class, etc.

I must also add that, for students to be engaged like this and to design these activities they need time. Time blocks hinder this. Also, especially in math, we have to deemphasize speed. Depth is much more important than speed. Too often teachers and students believe that the faster you can do math, the better you are in math. When we value speed (giving timed tests, limiting the time available, holding speed competitions, etc.) we may be encouraging students

Figure 9. Ruffing Montessori School, Rocky River, Ohio

who do math quickly but we may be hindering the slower (perhaps deeper) thinkers.

I read a blog post by author Annie Murphy Paul that started with the quote: "Leisure is the new productivity." She said that this counterintuitive slogan emerged from a panel she attended hosted by journalist Brigid Schulte. Schulte explained that our continual state of busyness prevents us from entering the loose, associative mental state in which unexpected connections and *aha!* insights are achieved. She drew her comments from the research of Northwestern University professor Mark Beeman, who found that although we may appear idle while daydreaming or mind-wandering, the brain is actually working especially hard in these moments, tapping a greater array of mental resources than are used during more methodical thinking. Schulte and Beeman contend that we need to make room for two distinctly different kinds of mental activity: the focused attention usually expected of us at work and at school, but also a more diffuse and leisurely state in which we are focusing on nothing in particular. We have to provide our students time to engage in both kinds of mental activity.

Figure 10. Ruffing Montessori School, Rocky River, Ohio

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