Cultivating the Scientific Mind: Montessori Science, Part II

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The continuation of this article, now referring to Upper Elementary-aged children and adolescents, is partly based on my notes from lectures in the Adolescent Orientation Studies in 2018, given by John MacNamara. Some phrases and sections are almost word-for-word John MacNamara's, so we can thank John for his generous wisdom!

John MacNamara was trained as a Montessori teacher in Bergamo, Italy in the 1970s by Mario Montessori's closest collaborator, Camillo Grazzini. John has been teaching classes of roughly forty adolescents in a combined seventh and eighth grade classroom at Ruffing Montessori School in Cleveland, Ohio for the past 47 years. As a mathematician and scientist, he often speaks to the integration of these two disciplines and to the wonderful ways that the Montessori approach of education allows children to explore and develop their minds with all disciplines interrelated.

Experiential Learning

In order to become a scientist, the learning cannot be abstract; children need to develop understandings by *doing*. Montessori educator John MacNamara emphasizes this point by saying, "Hopefully, there will not be a lot of teaching going on in my Montessori classroom, but there will be a lot of *learning*!"

In all of the presentations that a Montessori teacher gives, he or she works from the general to the specific, from the whole to the details. When children come to Upper Elementary Level, the expectation is that they will explore, propose ideas, learn how to organize and plan, and be intentional in their work. When the Montessori teacher sees that Upper Elementary children need a new piece of information to carry on their work further, he or she gives the relevant presentation—such as graphing, ratio, or how to make a chart to analyze and compare data—and the children can incorporate that new tool of knowledge into their repertoire.

It is important to recognize that this is backwards from the way we are used to thinking of schooling. But as a text book has already decided an order and what answers should be found, if the teacher teaches with a set list for every child, the child's energies will quickly disengage and go elsewhere. The child's energies want, by nature, to fix upon a path of his own designing, and so, Montessori teachers must notice children's interests and pepper the way in front of them with more wonderful nuggets to choose from. When a child grows up this way, exercising his will and his ability to choose, every day, he becomes a person who chooses, who directs himself, and pursues passions with purpose. The Montessori child has been allowed to find out how to steer himself, and so this is what he does into adulthood.

This is really quite simple, although most Montessori graduates think it odd that everyone they meet in adulthood isn't this way. I hear them say that they often wondered, "Why would I do something just to impress people? Why do people do that?" Montessori students don't learn the game of performing to get a grade and then remain disinterested in the content being discussed. That kind of boredom is foreign to them. Instead, Montessori children are doers, they are learners, and they are excited about life! They seek to understand, and they have years of experience pursuing new information to form their structures of knowledge. This is a direct result from the way they were treated as scientific learners with the Montessori approach.

What Students Do

The Montessori Elementary curriculum begins with science on the very first day of every year with the first Great Lesson about the universe, and the threads of scientific study and exploration continue every day in the classrooms. As the children work their ways down different paths of interest, the classroom becomes a rich breeding ground of questions and answers between the students themselves. In describing what has happened this spring in her

Upper Elementary classroom, Forest Bluff Director Regina Cyvas Sokolowski explains: “There are a number of constructions that came about from the children's own ideas; they may have been inspired from a conversation in a lesson or while talking with their classmates, but the beauty of the uninterrupted work period is that they are given the time to explore these ideas. Sometimes they bring in, or research, diagrams. Then they gather classroom materials or even bring in things from home to make their constructions.” Recent examples of such work include:

One group constructed an electric car. They brought in wheels, a 9 volt battery, and some wires from home and found towels, hot glue, cardboard, aluminum foil, and some other supplies in the classroom. By soldering and connecting the wires and lots of trial and error, they got it to move!

Another group wanted to construct a freezer. They had researched items that would serve as good insulators and had to tweak the original diagram they found which suggested using dry ice. Instead, they used many layers of cardboard, felt, and duct tape and then tested it by putting ice on one side and their lunches on the other. The ice did not melt, and their lunches stayed cool! For aesthetic purposes, they decided to add some LED lights and wheels so that it could be portable.

After a discussion of the scientific method and how to construct an experiment, a group of five children designed paper airplanes, which they tested over seven trials each and then averaged the distance traveled. They repeated the trials by adding some coins to the airplanes so that they would weigh more to see how it affected the distance traveled.

A number of children studied the heart and the circulatory system after a lesson on that topic. One girl traced herself and then did a life-sized drawing of the circulatory system. Another girl made models of parts of the circulatory system using clay and acrylic paint.

Earlier in the winter, some children chose to dissect baby sharks to investigate other body systems. They mail-ordered the specimens and made an appointment with a local surgeon to come be their resident expert to assist them at the school for their two-hour dissection.

Several students built pulley systems, following a brief lesson that introduced the concept of a pulley. Students explored the idea and those of other simple machines to create chain reactions. The class discussed the clever drawings of artist Rube Goldberg, and many students were further inspired from that discussion. As is the case with many things in a Montessori classroom, the children got excited by each other's ideas, so they had five or six of these chain reactions constructed within a few weeks’ time. Some of the children went on to build miniature gondolas and zip lines as a continuation. A few were even battery operated!

This is just a sample of scientific explorations, which ebb and flow and migrate into different subject areas over the months and years in our classrooms.

All such science activities are supported by the adults but not directed by them. The students direct themselves, and to witness this is inspiring. One morning, the three boys making an electric car asked me to be the adult to be present in the Parent Child room while they used a hot glue gun and a soldering iron. They had all their supplies laid out on a floor table, their face masks were in place, and they were ready to proceed. I did my paperwork off to the side but looked up and watched now and then, seeing that they were handling everything responsibly. I was so impressed! It was like watching three little men, and even their comments to each other demonstrated their maturity and focused states of mind:

"You are like a surgeon's assistant, you know."

"Yes, now, hold these wires here off to the side if you would, thanks."

"Careful, now; the wires are drooping there…"

"Oh! Are you OK? Sorry about that."

"Here we go. Please hold your hand steady. Don't move."

To watch the intense focus of these three boys, ages ten and eleven, and their smooth movements and collaboration was amazing. I noticed the fine motor control and finger dexterity necessary for such maneuvers, which Montessori students develop from their youngest ages with the Montessori materials and activities.

In the Secondary Level, the adolescents move through units of scientific study on topics of chemistry, physics, and anatomy, for example, although science is integrated into all aspects of the curriculum. Science relates closely with mathematics, for instance, because all of our math work and math seminars deal with scientific notation with exponents and scientific concepts.

Most importantly, “math encourages students to refine their reasoning powers,” Secondary Level Directors Matt Robbins and Elisabeth Miles explain. “They learn to question and to prove how they know what they know. There is an ethical development that happens through showing your work, being honest with yourself when you need help, and following through with your stated goals.” This ethical development transfers and relates directly to work in the sciences.

Spontaneous scientific exploration occurs in the Secondary Level as well. This semester, a girl studying music designed and conducted an experiment and then wrote the results in her Independent Study Project, following the structure of the scientific method. This past fall, students learned about anatomy and physiology by studying human body systems. They designed and conducted their own experiments with the scientific method and then embarked on a study of the human brain, involving a visit to Lake Forest College to meet with professor Shubik Deburrman and his team in the Neurons, Brains, to Behavior Lab.

Independent Thinking for The Later Years

With traditional science experiments for adolescents, the conclusion is already known before the students begin the experiment—the results and procedures to follow are already known as well. But with the Montessori approach, students ask the questions and determine how to proceed to find an answer. They develop an independence and a willingness to take risks, leading to real scientific thinking. They create their own experiments and practice scientific inquiry in action.

For example, math and science formulas are not the first things Montessori students learn, which is the pattern of teaching in conventional programs. In conventional settings, curricula, textbooks, and workbooks teach *formulas to memorize*. Instead, in Montessori, we present *strategies to develop*. Students work with strategies, and they develop their own unique

strategies as well. The students have to understand what is behind their strategies as they use them, which makes them really think things through. The formulas the students discover through their work are their points of arrival, giving them the thrill of discovery just as the first scientists felt.

We must always keep in mind that we are aiming to help children develop their own sets of strategies, not to teach them to memorize isolated strategies such as shortcuts, invented by others. This latter, popular approach of most science programs leaves students without the foundation they need to build for themselves. Think about it: if students forget the shortcut a teacher taught them, they will be lost. *This is why it is imperative that parents and other math or science programs not "help" our students by giving them shortcuts.* Shortcuts are wonderful strategies children will invent on their own if they are really engaged and ready to find them with their own minds. When we hand shortcut procedures over to children, we hand a crutch without the context and foundation the students needed to truly reach the epiphany for themselves. Every mind works a little differently, so each scientist needs the chance to develop their own strategies.

Framework Matters

Establishing a framework of information for each individual is important, too. Eventually, learning procedures without a conceptual framework will get you into trouble in science and math. John MacNamara tells us that Dr. Montessori said, "To teach details is to bring confusion. To establish relationships between things is to bring knowledge." In the Elementary program, we begin by giving students the framework of the entire universe with everything it holds. The basic laws of physics and chemistry that give our earth shape, gravity, states of matter, heat, etc., are presented to the children in a series of key lessons that help elementary students to form structures of knowledge and simultaneously ask questions they want

to find the answers to. In this way, our children are scientists from their very first day. They begin to develop the frameworks of scientific inquiry and how to set up research as well as experiments with a hypothesis, listing their materials, describing their procedures for what they plan to do, and reflecting on the results of what happened afterwards.

This practice, which begins formally at age six in the Lower Elementary, evolves to higher levels of sophistication by the time students are in middle school and can use more advanced equipment to inquire about their interests. John MacNamara tells of how his adolescent students wondered whether braces really do improve people's bite plates and straighten their teeth, and if so, do they differ from one another afterwards, or does everybody get the same mouth shape, essentially? The students thought about how to test this. They decided to collect records by asking students all through the school to bite on paper to make imprints of *before*, *during*, and *after* braces. This experiment involved many students and subjects over multiple years, and MacNamara required his adolescent students to be serious and official about their work, so the data they collected would be real. Needless to say, this was a lot of fun for them, and they learned a lot while doing it. Simultaneously, many other experiments were going on, but from these more gradual studies, students see how long it can take to get the results of some investigations. It takes stamina to return to the same ongoing study over multiple months or years. The thrust of the work is rooted in the students' curiosity. MacNamara says, "The role of Montessori education is to interest the student profoundly in an activity that he or she will bring all of his and her potential to."

Asking Original Questions, Pursuing Answers, and Expressing One's Findings

In Montessori programs, the teachers capture the children's attention and stimulate their thinking by asking intriguing questions and by demonstrations that show phenomena, without

providing answers. In guiding the students to access what they already know, Montessori teachers begin any new presentation by helping students to orient themselves. Students then want to fill in the new blanks by acquiring more information by their own research, experiments, and investigations.

The teachers help their students learn how to plan and carry out purposeful experiments that relate to their questions. They show them how to report what happened accurately, with the vocabulary and language that accurately communicates. Children are taught, from age six onward, how to design an experiment, repeat a scientific demonstration, and record their data. While very cursory at first, by age nine children are taught to transfer their data into graphs, tables, pie graphs, and other clear formats. By age twelve, students are shown how to present their data with percentages and ratios. Using these formats in such relevant ways makes them more meaningful, accessible, and familiar before students graduate to middle school.

Scientific Thought as a Natural Development

John MacNamara explains, "It is as ridiculous to think of math or science as a subject to be taught as it is to think of any ability to be developed. Do you say, 'I taught my child to talk?' or, 'I taught my child to walk?'" Try thinking of the development of children's scientific minds and mathematical minds the same way. We do not teach math and science to children; we give them the world to observe and wonder about, and through our linking them to interact with the environment—through their unique experiences and activities—our children develop themselves as mathematicians and scientists.

This is the beauty of Montessori education: we are not teaching children to go through the motions; we are treating them as the creating thinkers they are, developing their own thinking processes. These processes become the children's individualized ones, that make sense to them,

that they can understand, remember, use again and again, refine, and develop further as they add more experiences. Every day, our children are building their scientific minds and having fun doing it. And as John MacNamara says, “It is the not knowledge but the *act of learning* that grants the greatest enjoyment, in any subject.” When there is enjoyment, there is full engagement and a lasting impact. What more could we want for our children’s education in the area of science?