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Innovative and Engaging Approaches in a Middle School Science Classroom: Ideas to Capitalize on Student Interest

Shelley Wermuth[a]

[a]Marana Unified School District

Shelley Wermuth graduated from NAU with her Bachelors in Elementary Education in 2016 and her Masters in Continuing Education for Elementary Education: Reading Specialist from Northern Arizona University. Shelley is in her fourth year of teaching in the Marana Unified School District. Shelley has taught 7th grade General Education Science, 8th Grade General Education Science, 8th Grade Gifted/Talented Science at Tortolita Middle School in Tucson, Arizona. Currently, Shelley teaches 7th Grade General Education Science and the 7th/8th Grade Shark Tank Elective at Dove Mountain CSTEM K-8 in Marana, Arizona.

Abstract

The purpose of this article is meant to provide evidence and examples from an exemplary middle school science teacher's classroom with regard for using innovative approaches in STEM education. The author of the article suggests moving from a curriculum-centered paradigm to a student-centered paradigm. Strategies for integration in STEM education are discussed, and include choice-based centers, project-based learning, and small group instruction. The role of standards and curriculum are addressed with an emphasis on whole child, developmental practices, and meaningful/relevant activities in science education.

Key Words: science education, STEM, integration, student-centered strategies

Introduction

The days of worksheets and silent classrooms are over. Students are no longer content with sitting passively, taking notes, and listening to a teacher lecture. A changing world and the evolving nature of STEM education demand more of teachers than the traditional means of instruction. Furthermore, a whole child approach is necessary as it promotes an organic, holistic education that recognizes the various needs of children beyond just the academic realm. Through integration, centers, and project-based learning, students are able to experience a more meaningful, and relevant STEM education that fosters engagement and caters to the different developmental levels of students. Furthermore, these processes are driven by an inquiry mindset that approaches content from a constructivist paradigm and calls for learning to be situated in realistic, meaningful, and relevant settings. There are many ways that integration and project-based learning can be used in the classroom. This paper explores the experiences and activities offered in a dynamic, integrated, middle school science classroom, and how these activities foster authentic engagement and student interest in science.

A Brief Review of Literature

It is necessary to be innovate in education, and as part of the process of creating more dynamic learning environments, it is necessary to review and critique traditional practices. Some of the most common ways of teaching science and math (along with most other subjects) have revolved around lectures, worksheets, and textbook readings. Even the gradual introduction of new technological tools and programs has not shifted the instructional methods away from these traditional practices. Essentially, technology has served to create a digital arena for completing worksheets or worksheet-like tasks, which do not engage students in their learning, or take advantage of new pathways for learning through powerful technologies (Wylie, 2014). Additionally, according to Rolheiser et al. (2019), "students crave a more active classroom environment," and this necessitates a shift away from "traditional lecture-heavy" formats (para 1). Furthermore, worksheets impede "oral language development, creativity, movement, problem-solving opportunities and the sensory experiences necessary for brain development, human interactions and friendships" (Affiliated Services for Children & Youth [ASCY], n.d., p. 2). Worksheets also preclude opportunities for play, inquiry, deeper conceptual development, and active scientific investigations (Stone & Stone, 2013). Also, simple textbook readings fail to provide experiential, inquiry-based activities and they are not sufficient for conveying information in an interesting, engaging manner (Foley & McPhee, 2008; McKinney, 2013; Stambaugh & Trank, 2010). If traditional methods are not particularly effective in the teaching of science, technology, engineering and math, then teachers must adopt different, more dynamic approaches to capture students' interest. Traditional, teacher-led, direct instruction approaches may not lead to deeper conceptual knowledge, and therefore, a more engaging, inquiry-based environment is needed for STEM explorations (Jong, 2019). The American Association for the Advancement of Science recommends a more student-centered approach, rather than these traditional methods that have adversely affected students from underrepresented backgrounds especially (Romero, 2016).

A student-centered, whole child approach would involve active experiences, meaningful integrations, and authentic assessment (Morse & Allensworth, 2015). Furthermore, the teacher needs to engage students through divergent pathways that foster interest, intrinsic motivation, and active experimentation and investigation (Darling-Hammond et al., 2019). The strategies and activities described in the following sections provide examples of how one teacher used a more student-centered, active approach in the science classroom.

Centers

Centers are utilized in the environment to capitalize on student interests, inquiries, and explorations (McCarthy, 2014). These were used in the classroom every other week, and they also provided deep integration with other subject areas. The centers included writing, reading, social studies, math/coding, art/drama/technology, and science and engineering. Frequently, there would also be a play center, which offered students a place to tinker and learn science through the art of play. At each center there were many (ten or more) options for the students to work and explore. Each option or possibility was geared towards the larger unit of study. For example, eighth grade students explored through physics-based centers at the beginning of the year, then moved into chemistry centers, and finally biology centers. Seventh graders, using the new set of science standards for Arizona, worked through physics, the atmospheric cycle, the rock cycle, plate tectonics, the human body, and general biology/ecology.

How the Centers Worked

Students were called individually, one-by-one, to start working on centers. The centers were choice-based, and the order for who received their first choice of centers was tracked by the teacher. Each day, different students were called first to allow every student an opportunity to explore based on their interests. Because of the element of choice, some students consistently chose to go to the art center and perhaps never visited the science/engineering center. This was allowed by the teacher, as the students were still exploring science through art. However, in an effort to create a healthy environment that fostered diverse explorations, the teacher also implemented a maximum number of students for each center. Once the center was full, students would be asked to make another choice. The maximum number of students at a center was set at five, although that number was increased to six because of large class sizes. Every student had an opportunity to explore their first choice over the course of the unit, and all students had multiple opportunities to explore through diverse pathways of learning. Centers were completed collaboratively or alone. Again, the students had the opportunity to choose what and how they explored while also choosing to work in groups or not. The students moved freely through the centers with no overarching due dates or number of required center visits. They also learned that if they were off task during centers, they would not be as successful as they could be within the course.

While Centers were Happening

The center environment itself was not necessarily used to teach the required curriculum. Furthermore, the centers were not used in such a way that they were expected to teach the curriculum. Centers were used purposefully as an exploratory, investigative environment to foster engagement with the material in a variety of ways. In order to guide the students through a more focused curriculum, the students would be called to small group instruction with the teacher while centers were taking place. The maximum number of students for small groups was set at five so the teacher could sufficiently attend to each individual's needs during the course of the small group instructional time. The length of time for each small group was set at about five to eight minutes. This allowed the teacher to go through focused, guided instruction with the students. Furthermore, the students were not grouped by ability but rather by the students' interest in the subject. Students would always rise to the occasion when they were learning about something that was meaningful to them. This was purposefully done in order to avoid the negative effects of strict ability grouping, and helped to destigmatize students' feelings towards science. Having what seemed like random small groups that changed every day helped the students to avoid comparisons with other students on the basis of their academic ability. Everyone was on an equal level in this way. During small group instruction, students would have one of three guided lessons: a discussion, a mini lab or activity, or a mini formative. Note taking was never employed by the students, and never expected by the teacher. The days of students taking notes while listening to a teacher lecture are over. Students learn best through meaningful activity, and especially when they are interested in the material.

Integrating the Different Subject Areas

Integrating different subject areas with science is crucial for overall student learning (Brand, 2020). In fact, science naturally connects with other subject areas very well. Examples include reading/writing a lab report, calculating the speed/velocity/acceleration of Newton's 2^{nd} Law, or drawing observations. Science is dependent upon other subject areas to function, and this expands beyond the subjects in STEM or even STEAM. Furthermore, every child learns differently. They have unique needs and background understandings. Teachers can no longer expect every child to learn in the same way and at the same rate (Semrud-Clikeman, 2010). By using an integrated, center-based environment, students are able to explore science in ways that cater to their strengths. Science may not be their best subject, but ELA may be. The students can learn science through writing stories/plays, writing research papers, and writing poems. Students who need more activity can explore through the science and engineering center. Here, they can move around and build models without the fear of a teacher telling them to sit still in their seat and to be silent. The following sections describe specific classroom activities that promoted a high level of student engagement in science and fostered students' interest and intrinsic motivation.

The Cave

Students were required by the Arizona state standards to learn about the rock cycle and minerals. Instead of having students complete a worksheet or having them read about rocks and minerals in their textbook, the teacher created a giant cave in the classroom out of one-hundred, sixty-four-gallon, brown trash bags. Black butcher paper was used to cover the windows in the room as well. When the lights were turned off, the room was nearly pitch black. Routes were created within the cave, and each route was assigned a number and rocks/minerals. The students were placed in groups, and took turns exploring the different routes of the cave (they used their cell phone as a flashlight). Each student had the opportunity to crawl through the cave, and when they found a rock or mineral, they would pick it up and return to their group. The students then wrote down observations about the rock or mineral that they found. After the group noted their observations, the rocks and minerals were placed back in the cave, and another member would crawl through the cave. Once each group found all of the rocks/minerals in the cave, the students returned to the "camp" (another classroom) to examine their findings. At camp, they discussed similarities and differences between the different rocks and minerals.

After all of the groups had finished, the teacher led a whole-group discussion to further explore and refine their findings. The students were asked to hypothesize how the rocks/minerals were formed, and they used prior knowledge and inferencing during the discussion. Student responses were recorded on the board, and students had further opportunities to compare and contrast, classify, and group the rocks/minerals. Once the discussion was over, the students were given the names of the rock cycles and any corrections that needed to be made to the list of inferences were made.

Integrated Physics Activities: Rockets and Cars

Eighth grade students started the year by watching a video of the NASA Redstone Rocket tests. These were not all successful tests. Students would watch as rockets blew up, perhaps ascending for a short time. Some launches were successful. The students were shown these videos to demonstrate the nature of scientific and engineering endeavors, which are driven by “human curiosity and aspirations,” and sometimes result in devastating failure (Next Generation Science Standards [NGSS], 2013). These videos provided a launch point for students to explore aspects of problem-solving and engineering practices, and would help them set up their own rocket experiments. First, students were asked and given time to explore and research their own student-directed inquiries related to the videos. Once the students had discussed their initial research with the whole class, the teacher facilitated a discussion about the difference between open-ended and closed-ended questions. Specific attention was given to the validity of scientific questioning. In this way, students were engaged in initial authentic scientific processes as they related to physics and engineering.

The students then explored Newton’s 1st Law of Motion, which states, “an object at rest will stay at rest, and an object in motion will remain in motion, unless acted upon by an outside force.” Utilizing the center approach, students were able to play with Newton’s 1st Law. Through their play, students were able to explore the concepts in concrete ways. Next, the students began their 1st Law Lab. This lab contained a rocket made of graph paper and a straw. The students were actively engaged in measuring distances and applying their knowledge by identifying where Newton’s 1st Law was taking place in the activities. The students learned about inertia, gravity, mass, and balanced/unbalanced forces. All the while, the teacher was incorporating and reviewing scientific processes like the scientific method and the Nature of Science. The students then took this knowledge outside and played the game, tug of war. They applied what they knew of Newton’s 1st Law of Motion, observing the balanced/unbalanced forces. Then the students calculated for net force.

For Newton’s 2nd Law, “Force equals mass times acceleration,” the students used fizzing tablets and water to calculate for mass, acceleration, and force. The students measured a film canister and filled it so that the collected mass was 10.5 grams. Then the students measured how much the different sizes of tablets were in grams. The sizes for the fizzing tablets were as follows: a quarter of a tablet, half of a tablet, three-quarters of a tablet, and a full tablet. Starting with the quarter of a tablet, the students opened the canister, put the tablet in, put the lid back on, flipped the canister upside down, and waited for the canister to pop off of the lid. Meter sticks were taped to the wall (this was done outside) and students watched to determine the height reached by the canister, as well as the amount of time it took to reach that height. Once the students tested for all of the tablet sizes, the students calculated the acceleration of the film canister. After determining acceleration, the students used the measured mass to calculate for the force of the “rocket.”

For Newton's 3rd Law, "every action has an equal but opposite reaction," the students created rockets made of pipe insulator, foam trays, a straw, a zip tie, and a rubber band. The pipe insulator was cut into equal pieces (12 inches long). The foam trays were also cut into three equally sized fins. The fins were hot glued onto the foam. Then the straw was tied in a knot around the rubber band and placed into the foam low enough so the zip tie could be placed around the circumference of the rocket near the top. The zip tie was pulled tight enough that the rubber band could be pulled, and the straw would not come out of the foam. Students did two different tests with these rockets. These were called the "thumb vs. index finger" tests, which were accomplished by firing the rocket off of their thumb and off of their index finger. The students were asked to find the average distances for these tests and note them in their data table. Once the lab was over, the students wrote about how Newton's 3rd Law was used during the lab.

Finally, the students did two more activities to measure speed and velocity. These involved "distance divided by time/distance divided by time with a given direction." The speed lab involved miniature toy cars and poker chips. Each group was given a toy car, five fake poker chips, textbooks, and rulers. The textbooks and rulers were used to make the ramp for the car. Then, the students measured the mass of the car. They measured the distance and time for how long the car took to get from the top of the ramp to the farthest distance. The students then calculated the speed and determined if the mass of the car affected its speed. For velocity, the students participated in the "Velocity Olympics," where they were given certain lengths that they must travel and do a certain movement for the entirety of that length (e.g. speed walking, skipping, running, hopping). The students had been placed into groups, and their teammates used a stopwatch to determine how long it took for the students to travel in a certain direction. The direction changed for each test.

Cars. During the second quarter of physics instruction, the students were given the goal of creating a self-powered car with common household materials. The car needed to be able to navigate a track (electrical tape on the ground in the lab section of the classroom), and if it deviated, the students, who were placed in groups, would need to start over again. The track consisted of five straights, four turns, and one hill. When it came to the turns, the students' goal was for their car to make the turns on its own. However, if the students could not figure out a way for the car to turn on its own, they could mark the placement of the car, turn it, and put the car down so the car was facing the correct direction. Furthermore, the cars needed to move on their own without the use of batteries or motors. Finally, the cars could be not be bigger than a shoebox and needed to be planned and constructed in class. Students used shoeboxes, chip canisters, 2-liter bottles, or flat pieces of cardboard for their designs. Commonly used materials for propulsion were balloons, magnets, rubber bands, and mouse traps.

Once the car was built, the students tested their designs on the track, but they were not allowed to handle the car outside of the previously described rules. The students then calculated the speed of the car for each time it moved (at the end they calculated the average speed), measured using the metric system, and used their knowledge of Newton's 3 Laws of Motion to navigate the track. The students tested their car once, made modification, tested again, made final modifications, and completed a final test.

In addition to the strategies of centers and small group instruction, these activities presented multiple, integrated, active pathways for exploring the concepts of physics. The science activities were heavily integrated with math and engineering concepts, but also involved creativity, divergent thinking, problem-solving, and critical thinking. Students were highly engaged and were able to make meaningful connections between the activities and the often-complex nature of the concepts.

LA Smog

The Arizona science standards call for seventh graders to learn about the atmosphere and technologies that predict weather. The teacher decided to use problem-based learning to explore these topics and capitalized on student choice and interest in their planned solutions to Los Angeles' air quality issues.

The students were asked what they already knew about smog in Los Angeles. They were given time to list what they knew, and the teacher facilitated a discussion using the students' ideas. The issues were framed as complex problems that required creative, innovative solutions. Then, students were given time for authentic inquiries, which involved questioning, researching, and even hypothesizing.

After the problems with LA's air quality were identified, and students had a chance to investigate through their own research and inquiry, the students discussed possible solutions as a class. Their preliminary ideas were presented, and the students were then shown information about the "Forest City" that China is currently constructing to combat pollution. This planned city has over 40,000 plants and is estimated to produce 900 tons of oxygen. It would lower the average air temperature by a couple degrees as well. Students were given the task of utilizing some of the concepts from the "Forest City" in addition to their own ideas to come up with ways to implement solutions to the LA smog problem.

Since the students had done some initial research, it was time to put a plan in place. They were tasked with creating a solution that would reduce pollutants in LA's air, improve air quality, reduce smog, increase water vapor in the air, and reduce carbon dioxide levels. Using the project approach in addition to problem-based learning, students could present this plan in many different ways including slideshows, models (on presentation boards or building a scaled model), a research paper, etc... It was up to the students to present this plan to the "Governor" of California (the teacher). The teacher facilitated the planning process and asked students to begin their work.

Once the students had a plan, they had to determine the best way to support its implementation. Guiding questions included:

- How many plants will they have?
- How much fertilizer/dirt is required (Nitrogen Cycle)?
- How much water does each plant need (Water Cycle)?
- How many plants are needed to reduce carbon dioxide levels in LA (Carbon Cycle)?

- What type of soil is best for the plants chosen by the students (Nitrogen Cycle/Rock placement due to plate tectonics)?

A unique and innovative aspect of this project was that the students needed to present their completed plan to the "Governor" of California (the teacher) to gain support and funding for their project. The idea was that science is also interconnected with other issues including economics. The students needed to answer questions regarding their project that discussed the Carbon, Nitrogen, and Water Cycles, as well as address how they were reading carbon dioxide levels, water levels, humidity, air temperature, and pollutants in the air.

After approval and "funding" for their projects, students went through a series of "days" where they had to read outputs from technology predicting the weather. They would determine if their specific plans would have any effects on the ecosystem/air quality in LA. Finally, the students created a project of their choice detailing their plans and solutions. This project incorporated multiple strategies including problem-based learning, the project approach, and integrated not only multiple science topics, but social studies as well.

Conclusions

The nature of science, a changing world, and calls for innovative new approaches in STEM education have led to teachers adopting new instructional strategies that foster inquiry, engagement, and meaningful, relevant activity. Centers, integration and project-based learning are crucial strategies that will pique students' interests and foster authentic engagement in a modern classroom. Students engaged in these strategies were able to work through "real world" scenarios at their developmental level and at their own pace. Now more than ever, it is crucial for students to expand their interests, find meaning in what they are learning about, and take control of their learning. This is especially true of STEM education as teachers need to promote various pathways to explore science, integrate with other topics, develop scientific identity in their students, and promote a life-long love for science.

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