There is an Art to Teaching Science in the 21st Century

October Smith

Abstract For the last decade, there has been a push to integrate science, technology, engineering and math (STEM) in education. Recently, the inclusion of the arts into STEM has made a push for STEAM in the classroom. This integration of these subjects does not mean offering the individual classes at school, but rather blending all five subjects together for a topic of study. The importance of STEAM integration is having an impact on the workforce which is looking for graduates that are prepared by knowing how to collaborate, communicate, create and problem solve. These "21st century skills" are not something that can be taught overnight; instead, and they must be developed throughout a student's schooling. Because of the natural integration of the STEAM subjects and 21st century skills, they often go hand-in-hand when discussing best practices for teaching science. This chapter examines the history behind teaching science, such as its impact on the workforce today, the inclusion of STEAM and 21st century skills, and its influence on teaching and learning in the middle school classrooms.

Keywords STEM · 21st century skills · PBL · Creativity · Collaboration

Introduction

> Murray Gell-Mann, Nobel laureate in physics and avowed multidisciplinarian, made an intriguing claim about our time: In the 21st century, the most valued mind will be the synthesizing mind—the mind that can survey a wide range of sources, decide what is important and worth paying attention to, and then put this information together in ways that make sense to oneself and ultimately, to other persons as well. (Gardner, 2006)

We no longer live in a world where memorizing facts is the key to a career path. The ability to process information, determine what is valuable, and then use that valuable information accordingly will be what sets each person apart from another. The synthesizing minds will be the ones that continue to advance our knowledge

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base and technology growth. But how do we teach young students to effectively synthesize information? This chapter will examine the history behind teaching science, why it has an impact on the workforce today, the inclusion of STEAM and 21st century skills, and the role middle school plays in all of this.

Science Education

Science and art, theory and practice are often taught in isolated instances. Schools focus on each subject independently, each teacher with their expert knowledge in a particular area. Ultimately, this is not how the real world works. Jobs today are no longer routine factory jobs, and they encompass a wide range of skills. New employees are expected to enter the workforce knowing how to communicate, collaborate and generate creative ideas. This is a far cry from the factual knowledge-based curriculum that once proliferated the curriculum in the United States. Not only are educators responsible for the factual knowledge of all subject areas, but now they must also attempt to integrate subject areas, such as math and science, in a meaningful, applicable way, while encouraging collaborative skills among students.

Learning- A Timeline of Events

How people learn has been a topic of interest dating back to ancient Greek philosophers such as Socrates (470-399BC), Plato (427-347BC) and Aristotle (384-322BC). Philosophers and educators continued to study the topic of learning every century thereafter. Nonetheless, this section will start with a newly formed nation, just after the American Revolution. Thomas Jefferson (1743–1826), proposed a radical idea that children should have the right to at least 3 years of a public school education (Mondale, 2001). Although Jefferson did not get very far in his quest for improving education during his time in office, it did allow for others such as Horace Mann (1796–1859), to begin leading a reform in education. Mann's focus was on the physical conditions of the school buildings, citing things such as light, heat, and ventilation (Mondale, 2001), but he also noticed the lack of standardized textbooks. He encouraged a new system of "common schools" where children would receive an "equal chance in life" (Mondale, 2001). Public education continued to become more systemic and regulated as the years went by, and around the turn of the 20th century, learning theories became part of educational pedagogy. John Dewey (1859–1952) constructed a philosophy of education that compared to that of Plato's ideas (Cahn, 1997). Dewey believed that the scientific method was the basis of how all education should be taught.

Following WWII, the United States became a leader in industry and technology. Veterans were attending college on the G.I. Bill and the interest in science and math careers increased. Russia launched Sputnik and the US responded by putting a man on the moon. The 1960's saw another turning point in education, as many of the

nation's youths were disenchanted with the Vietnam War, leading to high social turmoil and a move away from established educational importance (Lederman, 2008). The value of education steadily declined until the early 1980's when "A Nation at Risk" was published. The message was harsh, citing declining SAT scores and indicating that schools were doing a poor job of preparing students for the workforce. This prompted supporters (and non-supporters) of the report to recognize that major changes to the education system were desperately needed. New reform efforts were launched, such as No Child Left Behind and Race to the Top, in an attempt to improve the quality of education. The beginning of the 21st century saw rapid changes and advancements in technology, bringing about new ideas for learning theories.

These new reform efforts needed to be analysed to ensure that the quality of education in America was actually improving from these educational changes. Thus, standard curriculum and standardized tests were implemented in every public school classroom. These standardized tests were criticized for narrowing the curriculum to a very specific knowledge set (Silva, 2009). If it could not be answered with a multiple-choice test, then it would not be asked—this was an idea that often eliminated higher-level thinking and creative thought. With the emphasis on standardized tests today, teachers need to find a way to teach the necessary subject content while infusing skills that will be needed for the future workforce.

Educational reform is a very slow process. To some, this may be a good thing as it allows educators to rely on tried-and-true methods and discourages the latest fads (Gardner, 2006). Others might enjoy the challenges that come with trying something new. Either way, we are doing our children a disservice by not moving quickly to facilitate acquisition of the skills they need to enter the workforce. Restructuring schools takes time and experimentation, allowing the culture of the schools to evolve and adapt, but it must be at a rate comparable to that of our society (Bassett, 2005). It is imperative that teachers design a curriculum that reinforces basic knowledge, while developing skills that encourages critical thinking among students (Bassett, 2005).

A STEM/STEAM Push

Concerns over declining STEM fields (science, technology, engineering, and math) launched the creation of the Perkins Career and Technical Act of Education in 2006. The Perkins Act provided funding for schools to improve STEM classes. In 2008, there was a big push to include the arts into the STEM fields, moving the term to STEAM. The integration of STEAM into education attempted to "balance technical expertise with artistic vision" (Peppler, 2013). STEAM integration is important because it provides students with real-life challenges rather than learning each part separately and having to put them together at the end (Wang & Moore, 2011). For the purpose of this writing, the term STEAM will be used with the understanding that the creative aspects of art integration are just as important as science, technology, engineering, and math.

Science and math are core subject areas that have customarily been taught in isolation since the early 1900's. The typical elementary class has one teacher that teaches all of the subjects to the students throughout the day. Larger elementary schools, with multiple sections per grade level, will often divide the courses based on teacher ability and comfort level. In one grade there might be a math, science, social studies teacher, and then the students will switch classes and have a different reading, language, writing teacher. This design allows for better integration among subject areas, but it does not always happen.

As students get older and move on to the secondary level, the subject area division becomes more defined. The structure of the secondary (middle and high school) education system puts students in a specific class, at a specific time during the day. It is a common practice in the US to hire teachers based on their expertise in a particular subject area. The push for STEAM integration becomes more complicated as teachers are used to being silos, teaching their content in their classroom, and now they are being asked to integrate multiple subjects including art.

Although content standards are set forth on the national or state level, educators continue to struggle with how to teach those standards (Bassett, 2005). This is one of the biggest challenges for STEAM, because there is no prescribed way of integrating STEAM subjects in the classroom (Wang & Moore, 2011). Currently, the STEAM subjects are taught independently, making curriculum integration challenging. It is not easy to integrate different subject areas together into one, especially at the secondary level.

When STEAM integration does happen, there is usually a primary subject area, and small tasks involving other subject areas are added to the activity. An example of this can be found in science, where students discuss simple machines, force, and motion using mousetrap cars. The primary subject is science, but students could easily design and engineer their own car. Alternatively, there might be a focus on two subjects, such as math and science, and the subject areas of engineering and technology can be added as the teacher finds appropriate (Roehrig, Moore, Wang & Park, 2012). In order to have the greatest impact with STEAM integration, major changes to the current curriculum need to be implemented. The Next Generation Science Standards (NGSS) is an attempt to address this issue by incorporating the engineering and cross-cutting concepts into the standards.

Teachers and Implementation

The educators in the classroom are the ones that are ultimately responsible for blending science, technology, engineering, art and mathematics to create a seamlessly integrated STEAM curriculum. With the engineering aspect built into the NGSS and technology being a part of our everyday lives, it would seem that integration should come easily in the classroom; but surprisingly that is not the case. Contributing factors to the lack of STEAM integration includes lack of training for teachers, little time to collaborate with other teachers, teachers sometimes having

a difficult time grasping processes in their own field of study, and difficult to make connections among core disciplines in general (Lederman, 2008).

Pre-service teachers spend a large amount of time learning the best practices for teaching students and the content knowledge comes second to this. During teacher education training, usually in college or an alternative teacher certification program, teachers focus on lesson planning, classroom management, and professional development. The best practices are broad and the intention is that teachers will be trained on specific aspects once they are on the job. However, with standardized testing, data analysis, and general campus procedure information, things like good pedagogy and STEAM integration get pushed to the side when it comes to in-service teacher training. It takes a dedicated teacher to seek out the training needed to learn what it takes to master STEAM integration.

STEAM integration relies heavily on teacher collaboration. Teachers must work together to come up with sound activities that stretch across the subject areas. Lack of time is a major reason why teacher collaboration is not very common (Gorder, 2008; Wang & Moore, 2011). Unless an administrator makes time for teachers to meet and plan together as a group, the collaboration does not happen as often as it should.

All educators have specific content in their area that they prefer to teach. It is a passion or love that extends outside of the classroom, making it easy to teach to the students. Content outside of a teacher's preferred subject area becomes more of a challenge and the students may not receive information at the depth necessary to fully grasp the concept.

Authentically assessing STEAM integration is a difficult task. It requires teachers to be more subjective, which is difficult since grades are typically derived objectively from worksheets and tests. Once again, teachers need time to collaborate and make tests that will accurately reflect STEAM integration and higher order thinking skills.

One thing to note is the theme that runs through this section. There is discussion about communication, collaboration, creation of materials and problem solving among teachers. Teachers no longer open up a textbook, have the students take notes, do the section questions at the end, and then give the pre-made test. While there may be books available to help with STEAM subjects, there is not a set of resources that give prescribed instructions on STEAM integration. These are skills that are not taught on the job, but expected. This begs the question, how are these skills learned?

21st Century Skills

Each part of STEAM is critical for the success of the other parts, as the subjects are intertwined. An emphasis should be placed on creativity, critical thinking, problem solving, communication and collaboration. These skills are important for students as they leave school and enter their careers. A growing trend of holding multiple

careers has emerged since the late twentieth century, and early twenty-first century. Considering the current trends in workforce training which indicates that people no longer hold life-long careers, but instead will change positions every 3–5 years, these career-readiness skills take on even more importance in preparing our youth for careers. “People can expect to have many jobs in multiple fields during their careers. Learning critical thinking leads students to develop other skills, such as higher level of concentration, deeper analytical abilities, and improved thought processing” (National Education Association, 2010).

The Workforce Then and Now

In 1940, most jobs were blue-collar jobs and the skills needed were learned at the job site. Three-fourths of all workers had never finished high school (Potter, 2002). In contrast, jobs today require a range of skills, such as organization and interpersonal skills that were not as essential several decades ago.

> Workforce skills and demands have changed dramatically in the last 20 years. The rapid decline in ‘routine’ work has been well documented by many researchers and organizations. There has been a rapid increase in jobs involving non-routine, analytic and interactive communication skills. (National Education Association, 2010)

All workers today need to be able to analyze information from a variety of sources and use the information to make informed decisions and create new ideas (Silva, 2009). These creative design skills are the most valuable within the job market today. Let’s use a teacher’s job for example. Educators are given numerous resources to use in the classroom, but it is up to the teacher to pull these resources together to best fit the needs of the students. This idea of pulling of resources and creating something new is becoming more prevalent; there is even a website called TeacherPayTeachers.com where teachers can buy other teachers’ materials.

Critics argue that teaching 21st century skills is meaningless and that educators should focus on core content knowledge rather than watering down the curriculum (Kereluik, Fahnoe, & Karr, 2013; Silva, 2009). What these critics fail to recognize is that without encouraging students to develop the 21st century skills at an earlier age, they would not be well prepared as they enter the workforce with communication and creative skills. It is hard to find a job that does not expect the employee to have communication and creative skills when they enter the job. Common interview questions are, “What project have you created from scratch and seen through to the finish? Who helped you with this project? How did you delegate the tasks for the project?” These skills can and should be taught in school so that the students are well prepared.

“In today’s world of global competition and task automation, innovative capacity and creative spirit are fast becoming requirements for personal and professional success” (National Education Association, 2010). This creative spirit is embedded in the open-source community. Open-source is the availability of a programs code to be freely used, changed and/or shared. Small groups of programmers have developed a wide range of software that falls under the open-source category. Linux is an operating system that is open-source and free. If Microsoft Office is out of your

price range, LibreOffice is a production suit that includes a word processor, spreadsheet application, presentation program and more.

Similar to open-source code, the creative commons licenses allow for sharing of other types of content. Wikipedia is an example of content that carries a creative commons license. Several collaborators work together to put out the most up-to-date free encyclopedia out there. This all takes communication, collaboration and a creative spirit to develop these ideas.

Outlining 21st Century Skills

In 2002, the NEA partnered with the Partnership for 21st Century Skills and created what has become known as the "Framework for 21st Century Learning" (National Education Association, 2010). The learning and innovation skills of the P21 Framework focus on creativity, critical thinking, communication and collaboration, all of which are essential for preparing students for the future. People today live in a technology rich world and have access to an abundance of information, rapid changes in technology tools, and the ability to collaborate and make personal contributions on a global scale. Students will need to be able to navigate an increasingly complex life and work experience in this globally competitive information age. In order to better prepare students for these life experiences, schools need to examine how they structure learning environments.

The typical elementary classroom today is set up in groups. Students work together and play together, especially in the lower grades. Enter a secondary classroom and you will see desks in rows. Students work quietly and individually. Generally speaking, this kind of structure with desks in a row and students working individually is typically not something done in the current workforce. Once students leave school, they will once again be working in groups to come up with creative new ideas. As schools reform to meet the 21st century skills, middle and high schools will look more like thematic based elementary schools, posing real-world challenges to students (Bassett, 2005).

Middle School is the Right Time

The objective of a middle school education should be focused on teaching students 21st century skills as well as gaining deep content knowledge (Kay, 2009). Middle school aged children (between 11–14 years old) are in a unique position. It is a time during those years that students become engaged and motivated to achieve in school (Kay, 2009). However, it is also during these years that students can begin to fall academically behind and no longer feel like achievement is possible, becoming unmotivated and disinterested in school. It becomes imperative that the teachers recognize the students that might end up in this situation, and work with them to provide a successful academic path.

One way to keep students interested and motivated in school is to find activities that engage them. There is a trend right now to incorporate a "genius hour" or "20% time" where students are given the freedom to work on a project/problem that they come up with. Depending on the parameters the teacher sets, students are free to choose anything they are interested in. Projects can range from designing a new type of foosball table to investigating the best types of grass for producing biofuel. If the teacher is cognizant of these "passion projects," they have the potential to successfully model what STEAM integration is about. Take the example of a foosball table mentioned above, the student must design (art, technology and engineering) and build (science, math and engineering) the game table.

Middle school is a time when students need to begin taking responsibility for their own learning. Middle school students should be ready for deeper inquiry, abstract thinking and exploration of the world around them. They have the foundational knowledge of learning, are enthusiastic, energetic and love working in groups (Kay, 2009). "As a result of students working collaboratively, the group can generate more knowledge, making collaboration a key ingredient to student success in today's global society" (National Education Association, 2010). The social and academic connections that students experience make middle school an ideal time for STEAM integration.

The Science Classroom Today

Science is the first part of STEAM, so let's spend some time examining middle school science. There is an art to teaching science in today's classroom. Story telling is an integral part of processing science, being able to tell who did what, why and how we know (Lederman, 2008). Education is no longer a sit-and-get environment as it was 50 years ago. The now, learner-focused classroom encourages students to problem solve and research through practical, real world applications. Challenges such as eCybermission, Siemens- We Can Change the World and Toshiba's- ExploraVision invite students to pose solutions to problems their communities face.

In keeping with this shift of pedagogical thinking, science instruction has moved from the teacher demonstrating in front of the class, to the students doing the demonstration themselves or in small groups. As part of this process, it is important that students understand that failure is part of the learning process, especially when learning something new. Focusing on real-world examples of problem solving encourages learners to have depth along with breadth. This gives them a genuine understanding of the problem solving process for similar problems and the skills they will need in order to face the career challenges ahead of them.

Middle School Students are not Experts…Yet

In traditional classrooms, the teacher stands in the front of the room lecturing. Students are given problems to complete outside of class for homework and then come

back and take tests that correspond to the work they did out of the textbook. If a person is only able to hold seven chunks of information at a time in short term memory, then the retention of the vast amount of information given during a lecture is questionable at best. "Traditional science instruction concentrates on teaching factual knowledge, with the implicit assumption that expert-like ways of thinking about the subject come along naturally or are already present" (Weiman, 2008).

The following lab scenario is common when thinking about a typical middle school science classroom. After the teacher has given lecture notes, a structured lab gives students hands-on experience. Students are asked to follow a set of instructions to complete the lab, and it is expected that the intended outcome of the lab would yield the same results for all the students if the lab is completed correctly according to the instructions. However, the fact is that science experimenting in everyday life is not a list of prescribed instructions, rarely are the students able to understand what they are testing. These "cookbook" labs increase student frustration when the results are not typical.

The more quality time is spent on practicing a skill, the more likely that skill will be mastered. This can be done through formal education, apprenticeship or self-directed learning. Once that mastery has been achieved, it is important to continue practicing that skill or it will be lost. Expert scientists have a vast amount of tacit knowledge to draw from. Middle school students do not have that vast knowledge…yet. Educators must be aware that while building that knowledge that will be stored in long term-memory, "we need to transform how students think so that they can understand and use science like scientists do" (Weiman, 2008). Middle school students should therefore not be treated like expert scientists.

Defining the Curriculum

The elementary curriculum is easy; students are learning how to learn. They are taught the foundations of reading, math, and writing. The high school curriculum is also defined, preparing students for college, digging deep into subject material. Middle school has no "galvanizing vision or goal around which to organize standards, curriculum, instruction, assessments and learning environments" (Kay, 2009). To complicate matters, the US education system is decentralized, so each state is responsible for the education of its students.

In April 2013, the NGSS was publically released and was developed by the states to provide science standards for K-12 that will include core content information, science and engineering practices, and crosscutting concept ideas. This is moving the curriculum in the direction of STEAM integration. However, since every state is responsible for its own standards, some states will choose not to adopt the NGSS. That means those states will be responsible for an alternative way to integrate STEAM into their educational curriculum.

One way to address STEAM integration and 21st century skills is through problem-based learning (PBL). Problem-based learning gives students the opportunity to work with a real problem and analyze it to come up with a solution for the problem.

Teachers are thought of as guides, leading the students down a path for a solution to the problem. Students typically work in groups and new knowledge is formed through self-directed learning as the problem is solved. Science is a particularly easy subject to incorporate PBL lessons since it is naturally conducive to solving problems. PBL is grounded in a constructivist philosophy where students learn by doing. "Every 21st Century skills implementation requires the development of core academic subject knowledge and understanding among all students. Those who can think critically and communicate effectively must build on a base of core academic knowledge" ("P21 Framework Definitions," 2009).

Activities that Engage

The most important aspect of engaging students in STEAM integration and 21st century skills is creating a learning environment that encourages students to explore and take risks. Students must feel comfortable enough in their learning environments in order to try different approaches to a problem that they previously attempted but failed to solve. Integrating a PBL environment can facilitate this type of learning. Although students may not correctly solve the problem on the first try, they will be practicing the process of problem solving and using different methods. The process is more important than the outcome.

Games From Word with Friends, to Angry Birds, games have become a standard app on electronic devices. The easy access to games provides an excellent way to incorporate STEAM activities into the class. *Minecraft* is an excellent free-play game that can be used in any subject area. The lego-type blocks in Minecraft can be used to create scenes and objects. Students may be asked in a physical science class to develop a car that prevents pollution and uses kinetic and potential energy in an innovative and efficient way. After using additional resources for research, the students, working in groups might come up with a car that uses magnets and wind for power. They can build the car in *Minecraft* while incorporating the concepts they have learned in class in order to explain their choice of design of the car. Math skills can be used to scale the car to size and an artist can render the final design.

Programming When surveyed, students unfamiliar with programming responded that programming was "hard and boring" (Repenning, 2013). By developing an avenue for students to be creative and take ownership in computer programming, teachers can get students excited about the process of learning programming. Programs such as Scratch and Alice have been developed to guide students through understanding the concepts of coding/programming. Scratch is a game coding program that was developed by researchers at MIT Media Lab. Students use a simple drag-and-drop interface to organize instruction bubbles that fit together like puzzle pieces to create a game. The Scratch website (scratch.mit.edu) has pre-made games and games that other users have made, and anyone can use the existing games to create new ones with similar coding. Similar to Scratch, Alice is another program that allows users to drag instructions to create a 3D animation or game. Whereas

upper elementary students easily use Scratch, Alice is a bit more complicated and is better suited for middle school students. Once students are comfortable with basic programming, they can begin to integrate the subject content into a project. For example, students can use Scratch to teach the carbon cycle by developing a drag and drop game that completes a "cycle" with the appropriate vocabulary game.

eTextiles A fairly new approach to programming is the avenue of e-textiles or wearable computing technology. E-textiles often require the knowledge of programming using math and science skills, as well as an artistic mind to create new designs. Users are able to design elaborate costumes that have embedded micro-controller boards, such as the Lily Pad Arduino (http://lillypadarduino.org), which is sewn into place with special conductive thread that connects to mini LED lights. The board is then programmed to turn the LED lights on and off, ultimately producing a wearable light show.

Conclusion

The education system in the United States has gone through many changes since its foundation in the 1700's, but there are still some things that remain the same. Commonalities include a board at the front, chairs with backs and standardized textbooks. These are just some of the physical things that Horace Mann so desperately wanted for his "common schools." Yet over the 250+ years, the educational pedagogy has changed. The beginnings were rooted in just getting children to learn to read. Today we expect children to read, write, solve problems, think creatively, communicate effectively, collaborate with one another, and more.

The 21st century is an exciting time to be living and working in! A strong educational foundation is important for all students to be successful in life. By providing students with collaborative experiences in science, technology, engineering, art and math, they are better equipped with the skill sets they may need for their future careers. In-service teachers must have the training and allotted time to effectively integrate STEAM collaborative experiences in their classrooms. Teacher and principal preparation programs must actively incorporate this STEAM integration training in their curriculum.

The goal of an education is to prepare students to be able to successfully navigate whatever career choice they might make. The workforce today is expecting to see employees that have excellent skills in communication, collaboration, creative thinking, and problem solving. By embedding these skills into content areas in the K-12 classroom, teachers can better prepare their students with these skills when they leave school.

Teachers must step out of the rigors of the standardized curriculum and tests in order to give students the opportunity to explore projects and interests beyond what is required. Passion projects have the ability to integrate, not only STEAM concepts, but also 21st century skills. Middle school is the ideal time to include "genius hour" and PBL activities because students are at the age where they are engaged, involved and feel personally responsible for their education. Other avenues to explore

beyond the curriculum to successfully integrate STEAM activities include games, programming, and e-textiles. Through all of this, science becomes an art to teach in the 21st century.

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