STEM Curriculum Best Practices in Selected Middle Schools

Masters Project

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Abstract

This study described STEM education in middle schools throughout Ohio. A total of 46 teachers were selected from the Ohio Department of Education's website directory of STEM-designated public and private schools. Of the 46 teachers contacted, 11 participated in one-on-one interviews. Objectives included describing the teachers' years of experience, grade levels and subjects taught, STEM best practices in pedagogy, STEM professional development experiences, methods to measure student growth, student outcomes, barriers to implementing STEM, and resources supporting STEM education. This qualitative study employed a semi-structured interview approach with open-ended questions and used a descriptive design to describe the current state of STEM education from a teacher's perspective in grades 4 – 8. The qualitative data were analyzed via a grounded theory approach to identify the emergence of themes and subthemes in teacher's responses. While schools varied in student size, teacher-to-student ratios, funding, student demographics, parental support, local business support, administration leadership in STEM, and teacher self-efficacy, saturation was achieved after 11 teacher interviews. Similar themes of best practices in STEM education within middle schools were identified in the perceptions of teachers through the interview responses. The need for quality professional development and training for teachers in addition to a supportive administration were 2 themes observed. Middle school teachers should implement the findings in their pedagogical design of their STEM classrooms. STEM education is a field full of acronyms and various terms that overlap and create potential confusion amongst stakeholders. More research should be conducted on creating a common language around STEM education to enhance effective communication, analyze student outcomes in STEM middle school settings, and designate best practices for curriculum and pedagogy in middle school STEM education.

Keywords: STEM education, STEAM education, middle school education, problem-based learning, project-based learning, student-centered approaches, constructivism, experiential learning, science, technology, engineering, mathematics

Introduction

"A motivated learner cannot be stopped" (Prensky, 2003). This revelation encompasses the essence of what STEM and project-based learning is all about. STEM education (an acronym for science, technology, engineering, and mathematics) curriculum and pedagogy is increasingly in demand for all ages of education. While STEM education has been around for decades, legislators, educational administrators, teachers, parents, and organizations recognize and are acting on its importance and implementation across our nation and Ohio schools (White, 2014). With key groups calling for STEM education across all grade levels, "STEM literacy is viewed as critical for the economic success and health of individuals and nations worldwide" (National Science Board, 2015; STEM Education Coalition, 2014).

I became interested in STEM curriculum when my son's public school asked me to participate in the advisory committee as a parent to oversee the creation of a STEM designated middle school for grades 4 through 8. As the principal waded through the funding and curriculum options available through the Ohio Department of Education and the close guidance of an existing STEM program in a neighboring school district, I wondered if this process could be streamlined. What are the barriers to implementing STEM curriculum in middle schools? Why is STEM programming important? What do students, teachers, parents, and administrators think about changing classrooms from a traditional focus to a STEM project-based learning focus? What are the benefits to students and our communities with STEM designated schools? This paper aims to investigate these questions in the framework of middle schools in Ohio.

Early exposure to STEM is vital, since interest in STEM can begin to blossom in elementary school. Early exposure to science can strongly influence future career plans. For example, engineering is a field critical to innovation (Beering et al, 2010). Experience with engineering activities (robotics and invention competitions) can spark further interest in STEM (Beering et al, 2010). This curriculum provides students the ability to "experience inquiry-based learning, peer collaboration, open-ended, real-world problem solving, hands-on training, and interactions with practicing scientists, engineers and other experts" (Beering et al, 2010). Developing our nation's human capital through innovative STEM curriculum in grades K-12 can prepare our students of today for the societal and business challenges of tomorrow.

Why is STEM important in U.S. schools?

It is important to our economy that schools be successful at producing students capable of talented contributions in STEM fields (Kettler and Margot, 2019). Understanding how the United States compares to other countries in higher education and research and development in science and technology fields is key. "In the United States, industry funds about 62% of research and development in science and technology" (National Science Board, 2008). "The low U.S. share of global engineering degrees in recent years is striking; well above half of all such degrees are awarded in Asia" (National Science Board, 2008). See figure 1 for a breakdown of higher education degrees in natural sciences, engineering, social sciences, and non-science and engineering fields in various countries.

Figure 1
Higher Education Degrees in Natural Sciences, Engineering, Social Sciences, and Non-science and Engineering Fields

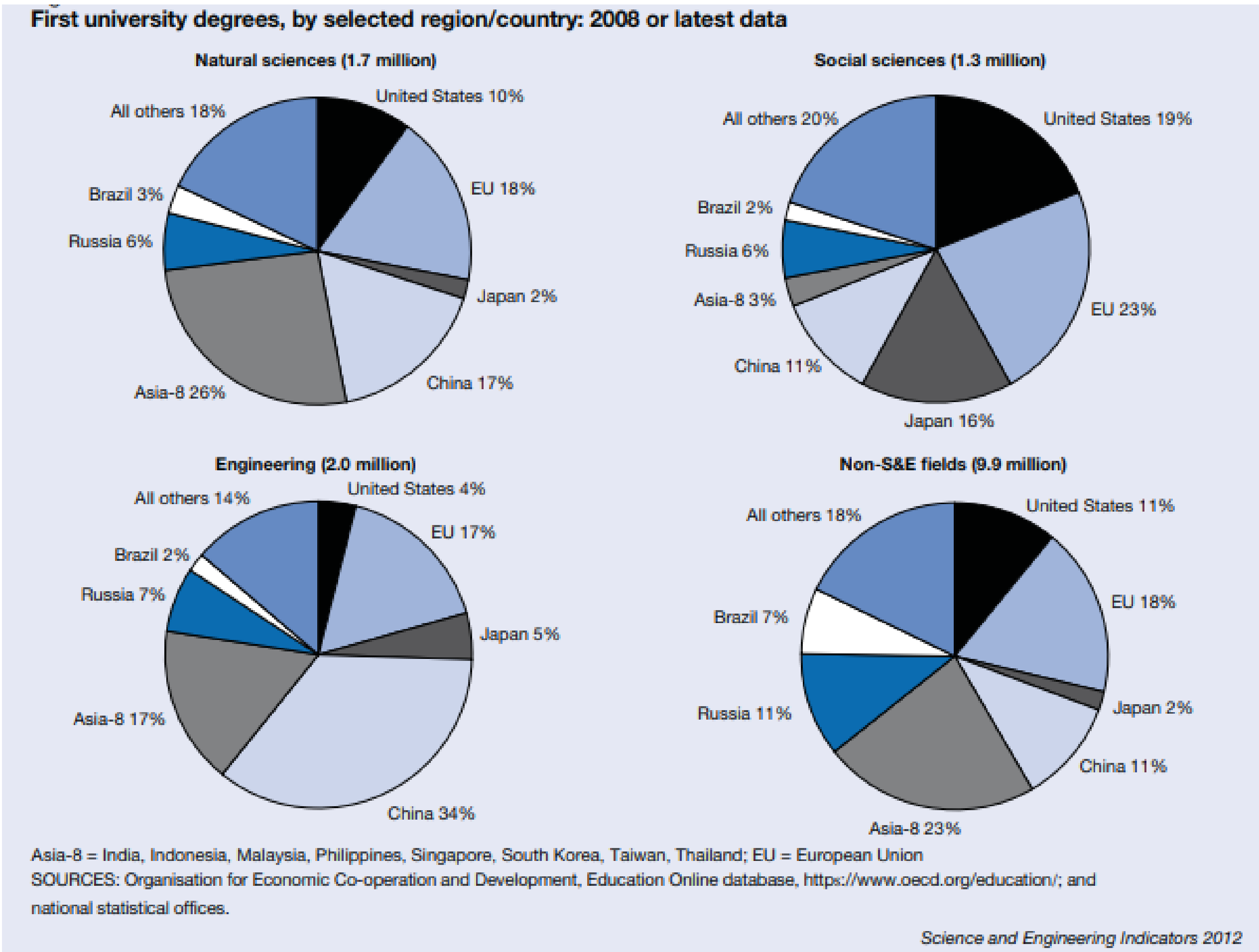
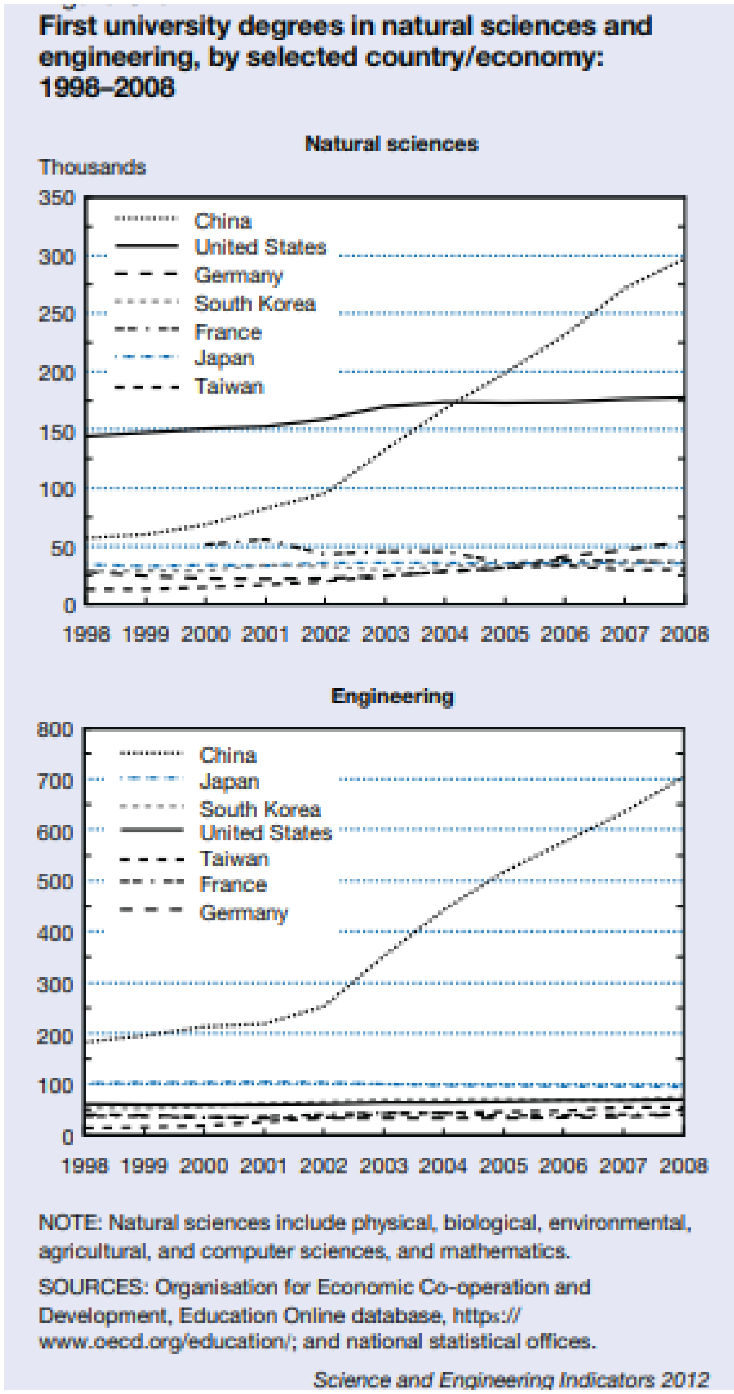


Figure 1 depicts the United State's stagnant position in students attaining first university degrees in natural sciences and engineering, while China is rapidly growing (National Science Board, 2008). Figure 2 highlights bachelor's degree attainment in natural sciences and engineering sorted by country.

Figure 2
Degree Attainment in the United States



Governments across the world are "holding firm in building science and technology into their development policies, as they vie to make their economies more knowledge and technology-intensive to ensure their competitiveness" (National Science Board, 2012). "These policies include long-term investments in higher education to develop human talent, infrastructure development, support for research and development, attraction of foreign direct investment, and technologically advanced multinational companies" (National Science Board, 2012). To remain competitive, the United States must prepare students in the K-12 setting for higher education degrees and careers in science and technology to meet domestic and global demand.

Students in the U.S. spend the majority of their educational time in traditional, formal classrooms. Course topics are siloed and connections between classes (between mathematics, language arts, and science, for example) are not commonly made (White, 2014). STEM curriculum attempts to link course content together for a full picture in the student's mind. STEM traditionally is more commonly found within informal (out-of-school) educational settings like summer camps, competitions, and clubs (Chiu, 2015). The National Science Board has stated that "formal and informal education are mutually reinforcing and are most effective when synchronized" (Beering et al, 2010). Informal STEM programs are effective, but access is limited, driving a need for K-12 STEM curriculum for greater access and inclusion. Through the use of emerging technologies, schools can access meaningful, enriching STEM resources. Via the internet, school districts can connect students to STEM experts, gain access to world-renowned museum collections, discover a vast array of digital STEM content, and participate in virtual laboratories (Beering et al, 2010). STEM curriculum is widely available.

Aspects of STEM Education

STEM in education is both a curriculum and pedagogy. The curriculum includes real world challenges for students to solve with interdisciplinary content. Interdisciplinary learning is "an approach to curriculum integration that generates an understanding of themes and ideas that cut across disciplines and of the connections between different disciplines and their relationship to the real world. It emphasizes process and meaning rather than product and content by combining theories and perspectives from two or more disciplines" (International Bureau of Education, 2021). Gomez and Albrecht (2013) advocate for grounding instruction in STEM pedagogy through an interdisciplinary approach. "This approach allows students to make real-world connections and prepare for STEM pathways and careers" (Kettler and Margot, 2019). Students must have intentional instruction into the connectedness of science, technology, engineering, and mathematics within STEM pedagogy. STEM literate means "(1) awareness of the roles of science, technology, engineering, and mathematics in modern society; (2) familiarity with at least some of the fundamental concepts from each area; and (3) a basic level of application fluency (the ability to critically evaluate the science or engineering content in a news report, conduct basic troubleshooting of common technologies, and perform basic mathematical operations relevant to daily life)" (Pearson, et al, 2014).

"STEM education includes student use of math and science concepts they have learned in an applied setting through the use of engineering design and technology" (Kettler and Margot, 2019). Instead of being taught in a vacuum, math and science are brought to life through their need to be used in order to solve a real problem (Chamberlin and Pereira 2017). Students in a STEM environment undergo a cyclical process of evaluating their solutions and then working to improve upon them. This revision step is an important part of STEM because it requires failure, improvement, perseverance, and the acknowledgment that solutions can always be improved upon. There is more than one answer to STEM challenges (Kettler and Margot, 2019).

Purpose and Research Questions

The purpose of this study was to identify best practices in teaching methods, curriculum development and implementation, resources, and professional development within STEM education in middle schools in Ohio. Additionally, this study sought to identify the leading methods of creating a project-based learning model focused on students constructing their own knowledge through interdisciplinary STEM subjects. Barriers to implementing STEM education were addressed. The following objectives posed to middle school teachers drove this investigation:

1. Identify the resources and barriers to creating and implementing STEM curriculum in middle schools in Ohio.
2. Explain how a project-based STEM model has the potential to increase student's critical thinking skills and improve student outcomes.
3. Define why STEM curriculum is important in today's middle school educational environment.
4. Describe how student growth is measured in a project-based STEM classroom.

Literature Review

To move forward within the field of STEM education, we should understand the history and context around STEM in the United States and Ohio. By analyzing the existing research in STEM, we can obtain knowledge of multiple aspects surrounding this educational approach.

Defining STEM

It is perceived that a student who participates in STEM Education, particularly in the K-12 setting, would have an educational advantage (Butz et al., 2004). Research has shown that "STEM education is effective in improving students' learning outcomes, such as academic learning achievement, student motivation, attitude and interest in learning, critical thinking skills, and problem-solving skills" (Saraç, 2018). One of the National Science Board's

2021 goals is to "improve the access to and availability of effective K-12 formal and informal education programs and interventions to meet the needs of future STEM innovators" (Beering et al, 2010). How is STEM defined in education?

With the diversity in programs and definitions of STEM, one is left wondering how do we define STEM? While definitions can transform and change based on the school's values and goals, the underlying principles of STEM curriculum are consistent through all STEM schools. The aim of STEM curriculum is to engage students in hands-on projects that are interdisciplinary, connected to solving real-world problems, tied to the local community, student-centered, and assessed based on topic mastery instead of a traditional letter grade. The goals for students in STEM education include STEM literacy, twenty-first century competencies, STEM workforce readiness, the ability to make connections among STEM disciplines, and engagement and interest (Honey et al., 2014).

A single worldwide definition of STEM education is not feasible or necessary, but educators working in the same system (school district, department, etc.) should "explore the common elements that are being attributed to STEM education to co-construct and implement a consistent vision that provides opportunities for all their students to attain STEM-related goals" (Holmlund, et al., 2017). Educators must push on the status quo in areas of "instruction, curriculum, learning opportunities, assessment, and school structures" (Holmlund, et al., 2017). "Sensemaking as a collaborative, reflective, and iterative process can surface the differences and commonalities in people's understandings to better ensure consistency in students' learning opportunities across classrooms" (Holmlund, et al, 2018). The National Education Association (NEA) conducted research and interviews asking education and business leaders the qualities needed to be successful in the 21st century. They determined the four most important skills are critical thinking, creativity, collaboration, and communication (NEA, 2016). Commonly called "the 4 C's," students experience these vital skills through project-based STEM educational models (NEA, 2016). What is possible to achieve in education if we arm our students with the proper STEM building blocks to create meaning and knowledge on their own through critical thought in the hands-on, project-based, interdisciplinary world of STEM learning?

"In order to capitalize fully on the STEM potential of our students, schools must streamline STEM education and refine their instructional pedagogy" (Kettler and Margot, 2019). An interdisciplinary approach will allow students to make real-world connections while preparing for STEM careers. This is the basis for STEM pedagogy (Kettler and Margot, 2019). Students learn by doing and are encouraged to develop new understandings while refining their ideas (Mooney and Laubach 2002). In the project-based learning process, students evaluate their solutions and then work to improve upon them in a cyclical manner. Revising solutions is an important step in the STEM process because it entails perseverance and the acknowledgement that solutions can always be improved upon (Kettler and Margot, 2019). STEM challenges have more than one answer and are open-ended.

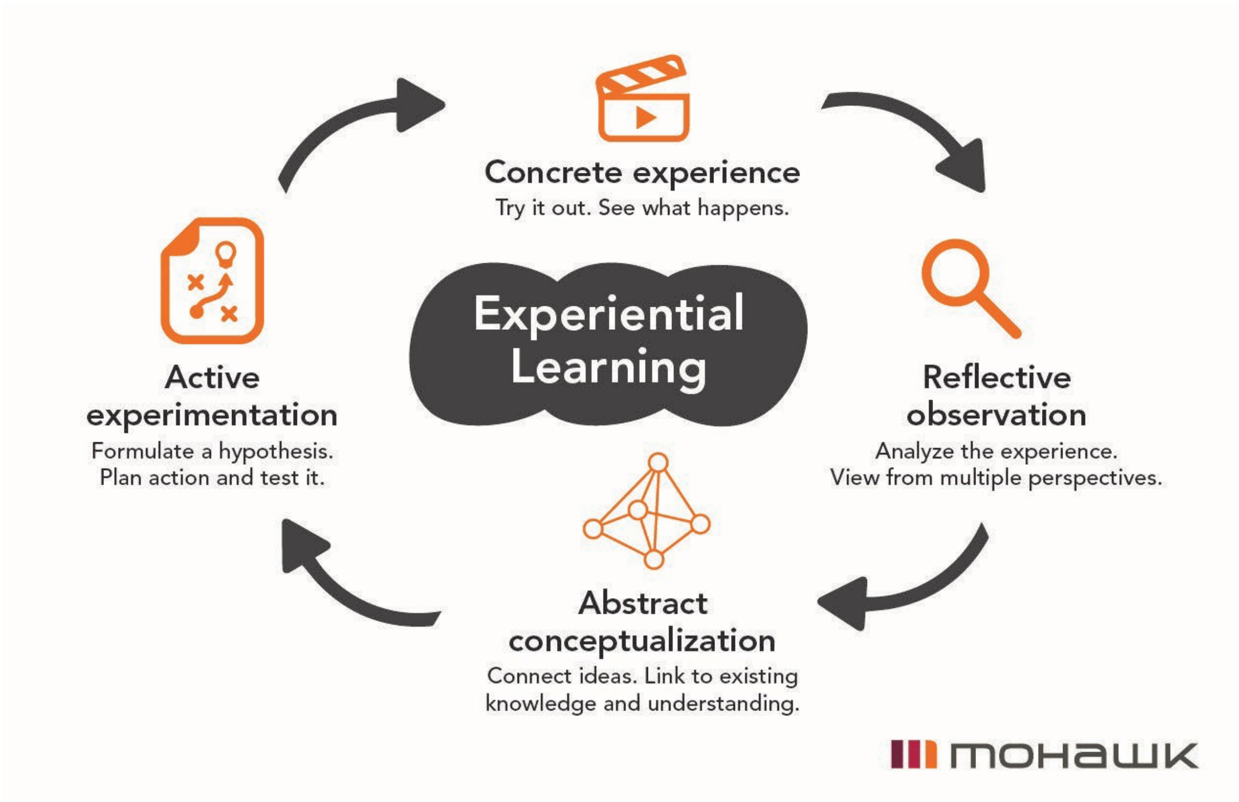
In a STEM classroom, the teacher guides students to analyze problems from all angles by questioning. Student-centered learning enables the student to construct their own knowledge through the process of creating and continually revising solutions to problems (Mooney, 2002). Teachers are there to facilitate this student-led process. By using hands-on, real world problems, content can become more exciting for students to solve their problems than from a traditional classroom with a lecture or workbook teacher-led pedagogical approach (Mooney, 2002). Teachers in STEM need to understand and value the power of the engineering design process to enable students to fail and persevere (Kettler and Margot, 2019). Teachers must know their subject matter, the content of other disciplines, the project-based learning model, and create an educational environment that supports students in the hard work of learning how to learn and think critically.

Learning Theories and their influence on STEM

Psychologist Jean Piaget proposed two learning theories (situated learning and constructivist learning) that form a foundation for STEM education practices. Situated learning theory advocates that students are more inclined to learn by actively participating in the learning experience in a real-life context (Piaget, 1970). Situated learning "takes as its focus the relationship between learning and the social situation in which it occurs" (Hanks, et al, 1991). The project-based learning approach of STEM fits with situated learning theory because students actively participate in the learning experience hands-on and through collaboration with their peers.

The constructivist learning theory states that "people construct knowledge through their experiences and interactions with the world" (Kara, 2019). Constructivism points out that experiential learning is more powerful than traditional learning (lectures, worksheets, etc.) Experiential learning is similar to project-based learning, and is defined as "learning by doing and reflecting on the experience" (Kolb, 1984). Constructivism theorizes that knowledge is constructed by the learner, not innate or absorbed. Learning is an active process and all knowledge is personal and socially constructed. Learning exists in the mind, and the goal of teaching is to provide experiences that facilitate the construction of knowledge (Kolb, 1984). Figure 3 shows Kolb's experiential learning model.

Figure 3: Kolb's Experiential Learning Model (Kolb, 2011)



Project-based learning is a constructivist pedagogy in which students learn more about a topic and develop critical thinking skills by solving real-world problems in small groups (Ram, et al, 2020). In the constructivist classroom, the teacher creates an environment where students are actively in charge of their learning. By helping students' scaffold (build off of) their experiences, teachers create a constructivist classroom environment. Teachers should encourage the pursuit of student inquiry, let students construct their own knowledge (active learning), work primarily in groups (collaboration), and view their role as interactive and a "guide on the side," instead of the "sage on the stage." A goal of the constructivist learning theory is to learn the process of learning and for students to possess self-awareness of knowledge construction (Driscoll, 2005). Students can test their own understanding against the understanding of peers through collaboration and trial and error (Driscoll, 2005). Reflection is a vital part of project-based learning. Reflection is "the analysis and synthesis of knowledge and activity to create new knowledge" (Indiana University, 2006). STEM education utilizes the constructivist learning theory and situated learning theory as guiding frameworks to implement project-based learning within the topics of science, technology, education, and mathematics.

The History of STEM

STEM education was originally called Science, Mathematics, Engineering and Technology (SMET) as an initiative created by the National Science Foundation (NSF) in 2001 (Sanders, 2009). The NSF is an independent federal agency created by Congress in 1950 "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense" by advancing knowledge to sustain America's global leadership position (NSF website, 2021). An original goal (that is still viable today, 23 years later) of SMET was to afford all students with critical thinking skills that would result in creative problem solving that transferred to a workforce with a more capable skillset. "In order to maintain its global leadership, America must ensure our citizens can meet the demands of a scientifically and technologically centered world. The NSF has a key role in creating and maintaining the SMET capacity in this nation" (Advisory Committee, 1998).

The acronym SMET did not take hold in education and a new acronym, STEM, was coined by the assistant director of the Education and Human Resources Directorate at NSF, Dr. Judith Ramaley, in 2001 (Chute, 2009). Dr. Ramaley defined STEM as "an educational inquiry where learning was placed in context, where students solved real world problems and created opportunities—the pursuit of innovation" (Daughtery, 2013).

The Ohio Department of Education's Role in STEM Designation

In 2007, Ohio enacted legislation to create STEM schools, an initiative designed to better align education systems to ensure sufficient intellectual, entrepreneurial, and technical talent for Ohio's future economic development (Domo, et. al, 2017). In 2017, the ten-year anniversary of this legislation, the Ohio Department of Education Office of Innovation assembled a STEM Innovation Working Group. The goal was to build upon ideas for next steps in STEM education in Ohio. The primary purpose of the STEM Innovation Working Group is "to assist the Office of Innovation in identifying where gaps in student readiness and teacher professional development may still exist, and in identifying priorities and common goals for STEM education" (Domo, et. al, 2017). The Ohio Department of Education STEM committee authorizes STEM designation for approved schools in Ohio.

In 2017, the Ohio Department of Education office of innovation created a 22-page quality model guide for STEM schools. The guide was created from the work of the STEM innovation working group, consisting of 47 STEM experts currently working on advancing STEM initiatives through non-profits, consulting companies, universities, research enterprises, teaching positions, administrator roles, and technology industry leaders. "Future economic growth and prosperity in Ohio depends on an aligned education system that supports the state's economic development efforts and helps all Ohio students to become innovators and inventors, self-reliant and logical thinkers, and technologically proficient problem solvers" (Domo, et. al, 2017). The working group identified the need for a quality metric for STEM schools, to ensure quality programming that promotes innovation and preserves the integrity of Ohio's goals for STEM education (Domo, et.al, 2017). The vision for the STEM innovation working group is that "Ohio will be recognized as a leading state in having a well-qualified workforce to attract STEM-related investments in business and industry. The mission is to create and promote initiatives that will pave the way for growth and economic development in Ohio, through multi-sector partnerships for STEM-related learning experiences for Ohio's students" (Domo, et. al, 2017).

The STEM Innovation Working Group identified three guiding goals: alignment, accessibility, and advocacy (see figure 4 for expanded definitions of the three guiding goals).

Figure 4: STEM Innovation Working Group's Guiding Goals

(Ohio Department of Education website, 2020).

Ohio | Department of Education

A Vision for Next Generation STEM Innovation in Ohio

Vision: Ohio will be recognized as a leading state in having a well-qualified workforce to attract STEM-related investments in business and industry.

Mission: To create and promote initiatives that will pave the way for growth and economic development in Ohio, through multi-sector partnerships for STEM-related learning experiences for Ohio's students.

Goals	**Alignment** *Align STEM Education efforts to regional economic development needs, emphasizing innovation and entrepreneurship.* • In PK-12 STEM education, enhance the voice of Industry, Higher Ed and other agencies, by increasing the degree of collaborative, active engagement in the preparation of Ohio's future STEM workforce. • Increase alignment of STEM educational programs to state and regional industry needs. • Increase emphasis and student participation in learning opportunities that focus on computer science.	**Accessibility** *Work to ensure that all students in Ohio have access to a high-quality STEM education, and promote STEM literacy for ALL students.* • Increase STEM designation participation, especially in Northwest and Southeast Ohio, and in rural or small districts. • Increase student participation in authentic mentorship, internship and research opportunities in STEM, especially for underserved students and students in rural and small districts. • Decrease barriers to STEM designation and STEM literacy. • Increase accessibility to highly qualified educators knowledgeable in STEM subjects, especially for underserved students and in rural and small districts.	**Advocacy** *Leverage and enhance existing networks to increase awareness and participation in quality STEM opportunities for students, educators and families.* • Collaborate with other state agencies, organizations, industry and local advocates to increase awareness of opportunities for students, educators and families to engage in STEM-related activities. • Increase awareness of various pathways to STEM careers available to students, including 4-year and advanced degrees, 2-year degrees, certificates and apprenticeships. • Increase awareness of the benefits of STEM literacy for all students. • Increase awareness of the benefits of STEM as a vehicle for deeper learning.
Strategies	**Partnerships** *Work collaboratively with the STEM Committee, the Ohio STEM Learning Network, higher education and other public and private partners to develop a long term plan for "next generation" STEM Innovation in Ohio.* • Create a STEM working group, to provide feedback to the department of education regarding greatest achievements and greatest challenges for STEM education in Ohio. Utilize feedback to drive improvement efforts. • Examine alignment of STEM educational programs to state and regional industry needs, and make recommendations for improvement. • Identify key indicators and pre-existing metrics and use them to monitor progress toward goals. • Utilize and enhance existing partnerships to identify and promote innovative and research-based best practices.	**Pathways** *Identify and promote various pathways to STEM careers available to students, and develop a metric for recognizing quality pathways and programs.* • Create/identify and promote STEM career pathways leading to 4-year and advanced degrees, 2-year degrees, certificates, and apprenticeships that promote the application of cutting-edge technology and the growth of innovative new industry in Ohio. • Consider an elementary designation. • Create metrics and programs for recognizing quality and level of immersion in STEM for schools, pathways, and programs, to encourage participation where a whole-school commitment may not be feasible.	**Preparedness** *Work collaboratively with higher education, ESCs, and other partners to provide support for teacher recruitment and preparation for teaching STEM subjects.* • Define and approve "high quality" teacher licensure programs and pathways for STEM educators. • Create/identify and promote externship programs with industry partners for teachers and leaders to experience content as it is applied in industry and to engage in industry research and development projects. • Utilize teacher-leader networks, local advocates, and peer-to-peer role models in providing local professional development and support for STEM educators. • Provide focused professional development opportunities to teachers for improving STEM content knowledge, including computer science.

The first goal is to align STEM education efforts with an emphasis on innovation and entrepreneurship to support regional economic development needs though collaborating with industry and higher education to prepare Ohio's future workforce. The second goal of accessibility works to ensure all students in Ohio have access to high-quality STEM education with an emphasis on underserved populations in rural or small districts and specifically northwest and southeast Ohio. Within accessibility, the need exists to increase student participation in authentic mentorship, internship, and research opportunities in STEM. Highly qualified educators who are knowledgeable in STEM subjects need to be accessible to all school districts in Ohio. The third goal of the working group is increasing STEM advocacy. Advocacy centers around increasing awareness and participation in quality STEM opportunities and highlighting pathways to STEM careers through apprenticeships, certificates, 2-year degrees, 4-year degrees, and advanced degrees (Domo, et. al, 2017). The benefits of STEM literacy for all students needs to be communicated for STEM initiatives to take hold. An overall big-picture goal of STEM education is realizing its potential to create deeper learning through project-based, hands-on experiences.

The STEM innovation working group also identified three guiding strategies to make Ohio STEM proficient: partnerships, pathways, and preparedness (see figure 4). Partnerships include working collaboratively with the STEM committee, the Ohio STEM learning network, higher education, and other private and public partners to "develop a long-term plan for next generation STEM innovation Ohio" (Domo, et. al, 2017). The STEM innovation working group delivers recommendations about the greatest achievements and challenges for STEM education in Ohio. This group analyzes the alignment of existing STEM educational programs to state and regional industry needs and continually adjusts with curriculum improvements to meet these needs. The first strategy is to utilize partnerships to "identify and promote innovative and research-based best practices" (Domo, et. al, 2017). The second strategy is to identify and promote various pathways to STEM careers for students through higher education. Another area of focus is creating STEM programs and awareness in districts where a whole-school commitment may not yet be possible. The final strategy is preparedness. Preparedness focuses on maximizing teacher's professional development activities that connect classroom content with current industry needs, produce high quality licensure programs for teachers, and collaborate with higher education and other partners to increase teacher preparedness.

In 2020, Ohio had 3,546 public schools of which 51 held the Ohio STEM designation (Ohio Department of Education, 2020). A total of 79 schools in Ohio are STEM designated. Of the STEM designated schools, 51 are public, 21 are private and 7 are STEM-specific schools. To achieve STEM designation from the Ohio Department of Education, schools must follow an application rubric and apply by the annual deadline. The STEM committee and Ohio STEM learning network review and approve or reject applications.

STEAM (A for Art)

The idea of STEM has been expanded in more recent years to include an "A," the arts, to become STEAM. By examining how art education can be a major and critical component of STEAM curriculum, researchers can gain deeper insight into the benefits of STEAM curriculum versus a STEM curriculum. Educational and political leaders want to invest in programs that promote innovation and creativity to solve twenty-first century problems (Daughtery, 2013). Recent studies have suggested the importance of developing "educational programs that engage both the right and left hemispheres of the brain" (Daughtery, 2013). In his book, *A Whole New Mind*, Daniel Pink (2005) urged readers to foster and strengthen creativity and innovation. He noted that our society is transitioning from the "Information Age," powered by the logical, sequential and analytical left side of the brain, to a "Conceptual Age," powered by the inventive, innovative, and creative right side of the brain. (Daughtery, 2013).

Some believe that education "leads to innovation, which leads to a strong economy" (Catterall, 2017). STEAM modes of learning make "students more creative and more empathetic, leading to happiness" (Catterall, 2017). "The same brain pathways that light up when students feel empathy are used working with art" (Catterall, 2017). At the federal level it has been made clear that the government values the importance of art education in preparing students for successful future careers. On December 15, 2015, President Obama signed the "Every Student Succeeds" act into law. The law included mandates and funding to provide STEAM education in schools.

Art education can increase creativity and empathy by creating excitement and providing students with a desire to learn (Catterall, 2017). While there are endless amounts of blogs, books, and websites proposing STEAM art projects, the original goals of art education and how it works to advance STEAM concepts are important to acknowledge. Allowing students (through art) to express and identify with their own individual creativity through the course topics of science, technology, engineering, and mathematics is a goal (Catterall, 2017). Bringing these topics to life in an art project that is hands-on and interactive for students with open-ended, multiple outcomes is another goal (Catterall, 2017).

With the goal of students gaining twenty-first century skills, the arts can connect disciplines in ways that are powerful and motivating for learning. The arts can be used as a tool to teach scientific, mathematics, engineering or technology concepts more fully by having students work and think across the arts and sciences and inspiring them to be more divergent, creative thinkers across disciplines (Henriksen, 2014). By learning content in more engaging and meaningful ways, two subject matters can strengthen each other in a learning scenario with interdisciplinary connections. (Henriksen, 2014). Art can be an integral way to connect concepts and enhance learning, interactivity, and fun in the STEAM process.

An example of incorporating art into STEM topics to gain deeper understanding in students is a program called geometry in motion. Geometry in motion is an educational activity that allows students to "experience dance as it integrates with principles of geometry" (Center for arts inspired learning, 2021). Middle school students form geometrical shapes with their own bodies, set to music and with guidance from a dance coach. The goal is to teach geometry concepts while engaging the psychomotor and cognitive domains simultaneously. Remember that "a motivated learner cannot be stopped" (Prensky, 2003). The arts can help fuel student motivation.

Relevance of STEM in Higher Education

In February 2021 at The Ohio State University, OSU President Kristina M. Johnson, PhD delivered her state of the University address. Two of her key initiatives included STEM topics. In her address, she identified a goal of having a better student-to-faculty ratio for an improved academic experience by hiring 50 new faculty in "racial equity research and scholarship in education (with particular emphasis on STEM)" (Johnson, 2021). Ohio State created a new Innovation District which is a "comprehensive unit focused on research, innovation and the knowledge enterprise" in connection with entrepreneurship opportunities and private-sector partnerships. (Booker, 2021). The goal of the Innovation District and recent funding is to "help increase sponsored research in biomedical science and engineering by 50% and to educate 22,500 STEM graduates over the next 15 years" (Booker, 2021). A leading land-grant institution, The Ohio State University is putting a focus on STEM education, research, and opportunities with the private-sector. Ohio State's STEM focus further highlights the need for STEM education in the K-12 school setting for students to prepare for their collegiate careers.

STEM Resources

How can K-12 school districts connect with the available STEM resources? The prerequisites to creating a STEM program include having a school district and community culture that enthusiastically supports and pushes for STEM curriculum, implementation of teacher training and professional development, utilization of STEM resources to the fullest extent, and leadership in school administration to guide the process. School administrator, teacher, student, and parent buy-in and the creation of a supportive school culture around STEM is essential for a successful program to get off the ground. A longitudinal study published at the University of Chicago highlights principal leadership and its impact on school success or stagnation (Bryk, et al., 2010). "Principals improve teaching and learning through their influence on staff motivation, commitment, and working conditions. Principal effectiveness plays a large part in school effectiveness and in student performance" (Leithwood & Riehl, 2003). "Support of STEM education is more successful when principals drive and support the school components and change needed in schools" (Chiu, et al., 2015)

Connecting the vast array of STEM resources (including non-profits, available grants, University and College ties, and local industries) with school administrators is a first step in the exploration process. "Resources go beyond money, and a regional partnership can provide access to stakeholders that are able to pull together resources and expertise" (Basham, 2010).

Best Practices

Researchers in 2014 conducted an extensive review of published literature, analyzed documents of state content standards, and consulted with experts in STEM fields to discover the ways teachers best utilize STEM education in their classrooms (Moore et al, 2014). After this exhaustive search, the researchers designated a framework that includes six major tenets for quality K-12 STEM education. The tenets are: the inclusion of math and science content, lessons are situated in engaging and motivating context, student-centered pedagogy, inclusion of engineering design or redesign challenge, students learn from making mistakes, and teamwork is emphasized (Moore et al, 2014).

The Role of the Teacher in STEM

Teachers are the single most important factor in the equation of STEM education (McMullin and Reeve 2014). Curriculum is simply a blueprint, and STEM education requires a pedagogical shift to student-centered learning. Much of the instruction is inquiry-based and experimental. It is paramount that administrators and policy-makers discover the barriers teachers believe impede this effort to develop STEM talent in classrooms (Kettler and Margot, 2019). "A dynamic teacher with a positive attitude toward STEM seems to be the single most important factor to implementation fidelity and STEM program success" (McMullin and Reeve 2014).

To enhance the learning infrastructure support system for students, schools should improve educator preparation and encourage a culture that values academic excellence and innovation in schools, families, communities, and the Nation (Beering et al., 2010). For school districts embarking on creating a STEM designated school, professional development of teachers is vital. The administrator's ability to provide sufficient professional development opportunities for teachers was ranked as "the greatest need to achieving their goals for STEM curriculum development and instructional implementation" (Shernoff, et al., 2017).

The National Science Board identified 8 goals to "provide opportunities for excellence" to students engaging in STEM curriculum. Goals include:

- Supporting rigorous, research-based STEM preparation for teachers, particularly general education teachers, who have the most contact with potential STEM innovators at young ages.
- Attention should be given to training teachers in the most effective methods of teaching STEM content, including hands-on and unstructured problem solving and inquiry-based learning.
- Teachers must be well prepared and enthusiastic, and possess both exceptional subject content mastery and special pedagogical preparation for working with students (Beering et al, 2010).

Teachers believed they had a lack of subject matter knowledge concerning STEM content with inadequate pre-service and in-service training (Margot & Kettler, 2019). They needed clarity about how the program was intended to be implemented into existing programs (Nadelson & Seifert 2013). "Professional development is a factor that affects motivation. Research shows that providing staff development will eliminate misunderstanding and give necessary support for all stakeholders" (Hope & Pigford, 2001). Other challenges included not feeling fully prepared to integrate STEM subjects (Al Salami et al. 2017). Another hurdle was a lack of instructional resources available (Park et al. 2017). "Although teachers deemed STEM education important and valuable, they were not comfortable with meeting the high teacher expectations they felt were associated with STEM" (Margot & Kettler, 2019). Feeling unsure about one's ability to teach STEM could lead teachers to a reduced confidence in their teaching efficacy (Bagiati & Evangelou, 2015; Clark & Andrews, 2010; Holstein & Keene, 2013).

McCormick Middle School

In January of 2021, the McCormick Middle School principal was interviewed. My children attend school here and I am on the STEAM advisory panel providing a parent perspective. The school is in the middle of the application process for STEAM designation from the Ohio Department of Education. The goal is to receive approval and implement the STEAM model through the non-profit Project Lead the Way in the 2021 – 2022 school year.

The principal identified three major components to implementing STEAM at McCormick (educating grades 4-8). Creating a culture for learning, emphasizing learning and teaching, and creating a project-based learning assessment of student work are the three components of STEAM he highlighted (Participant 11, January 12, 2021).   The school's administration (the principal along with the superintendent) must create a supportive and innovative culture. This culture will provide teachers with the appropriate professional development tools, assistance in connecting to teachers as mentors in similar grade levels at neighboring STEAM schools, and support through leadership and flexibility as teachers grow and adapt their classrooms to the project-based learning STEAM model (Beering et al, 2010). Going from a traditional classroom that is teacher-centered to a STEAM classroom that is student-centered will be a transition that presents growing pains and a learning curve for administrators, teachers, and students. Support and guidance from administration will be imperative to success.

Through setting an accessible vision and leading the same charge, the principal hopes to create a supportive environment that focuses on individualized learning for each student. This can be accomplished through interdisciplinary standards and curriculum. Creating projects for students to work on that combine English language arts, math, and social studies into one project is preferred in contrast to subject areas being taught in individual compartments. Another key to success will be bringing in speakers who will share their professional work experiences to open student's minds to potential future careers and opportunities. By establishing real-world partnerships with the neighboring vocational high school, community college, and local businesses, the principal wants to show students how their STEAM curriculum can be put to work. Field trips, projects, and demonstrations through these local partnerships can bring to life how STEAM connects to solving existing problems in education, government, and business.

"The long-term goal of STEAM at McCormick is the longevity and staying power of STEAM in the school district. We are starting with grades 4 – 8 at McCormick, then we will work to develop continuity by bringing in the elementary and high schools. It is important to keep the continuity from middle school to high school" (Participant 11, January 12, 2021). The high school focuses on student preparation for different career tracks. Having a strong foundation in STEAM curriculum in elementary and middle school will prepare students for their pathways in high school and beyond.

The principal stresses the importance for teachers and students to exhibit a growth mindset versus a fixed mindset. "Growth mindset is defined as a belief that construes intelligence as malleable and improvable. Students with a growth mindset work hard and improve without an incentive reward as the outcome" (Ng, 2018). For the development and implementation of STEAM in the middle school, administrators, teachers, students, parents, and the community must have buy-in of the overall school culture (Al Salami, 2017). Being accepting of a project-based learning STEAM curriculum approach is important to create a school culture that is conducive to growth and learning. Focusing teaching on encouraging students to dig deeper into the analysis of projects and content and developing vital critical thinking skills is McCormick's goal. Moving away from a traditional A, B, C, D, F grading level toward a mastery form of grading is imperative with STEAM education (Participant 11, January 12, 2021).

Methods

This study utilized a qualitative approach to gain an understanding of STEM schools in grades 4-8 in Ohio. The purpose of this research is to describe the current state and best practices of STEM schools. Identifying the perceptions of teachers in middle schools allows a closer look at how STEM works in the classroom. The following objectives posed to middle school teachers drove this study:

1. Identify the resources and barriers to creating and implementing STEM curriculum in middle schools in Ohio.
2. Explain how a project-based STEM model has the potential to increase student's critical thinking skills and improve student outcomes.
3. Define why STEM curriculum is important in today's middle school educational environment.
4. Describe how student growth is measured in a project-based STEM classroom.

Instrumentation

The research goals of this study were to have teachers in STEM classrooms describe best practices, methods for assessing student growth, professional development experiences, helpful resources, and identify challenges and barriers. With these goals in mind, 18 research questions were initially drafted. Under the guidance and revisions of 2 faculty members at The Ohio State

University, a framework was formed around 5 key areas. The key areas of questions were: an introduction, establishing the teacher's background, STEM teaching methods, best practices, and barriers. Questions regarding diversity and inclusion were removed due to irrelevance to the research goals.

A faculty member with experience in qualitative and quantitative research who teaches a graduate evaluation class revised the questions down to a total of 13. Using the word "describe" at the beginning of a question was a change to gather deeper insights. The introduction included an ice breaker question (would you rather live in the mountains or on the beach?) and the interviewer's background and reasons for pursuing research in STEM education. Next, demographic data was gathered with broad, simple questions and progressed into deeper questions about STEM pedagogy. A second round of revisions were made with two faculty members from The Ohio State University. The questions were reviewed by a middle school teacher that was not a part of the interviews to ensure they were conversational and simple to understand from a teacher's perspective. Revisions were made from the teacher's feedback and a final list of questions was compiled, reviewed, and utilized. Interview questions can be found in Figure 3 on page 29.

Data Collection

Within this qualitative study, a semi-structured interview format as the primary data source was used to interview 11 teachers across Ohio. Semi-structured interviews gather in-depth responses through the use of pre-established, open-ended questions with the ability to follow up to responses and dig deeper to further understand the meaning of responses (Wholey, et al., 2015). The interviews ranged from 25 to 50 minutes in length. Interviews were conducted over a span of 2 weeks. The first interview was on February 24, 2021 and the last interview was on March 10, 2021. Teachers were chosen from the Ohio Department of Education's website of STEM-designated public and private schools in Ohio. After viewing the school's website and finding STEM teachers through the staff directory or a phone call to the school, 46 teachers were emailed asking for their participation in a 25–50-minute Zoom call for research on best practices in STEM education. Of the 46 teachers emailed, 11 chose to participate and signed up for a time slot utilizing the website Sign Up Genius.

A faculty member at The Ohio State University was asked for suggestions of STEM teacher contacts. Of the faculty member's recommended teachers, 2 participated in the interview and their schools were verified as being designated STEM schools by the Ohio Department of Education. Participation in the interview was entirely voluntary.

The principal at McCormick Middle School was also interviewed on Zoom for an administrator's perspective. A Zoom link was then emailed to the teacher, along with a thank you email following the interview. Zoom interviews were recorded for review and data collection. Due to the Covid-19 pandemic, many teachers engaged in remote learning on Wednesdays. Wednesday was a popular time for interviews due to the flexibility of the teacher's hybrid schedule. 10 teachers were female, 1 teacher was male. The following 13 open-ended questions (figure 3) were asked during the interview, with follow up questions asked as needed for increased clarity.

Figure 3. Qualitative Research Questions for STEM Teachers

Teacher Background

1. How many years have you been teaching?
2. What grade(s) do you teach?
3. What subject(s) do you teach?
4. How many years have you been involved with teaching STEM?

STEM Teaching Philosophy

5. What do you like best about teaching STEM?
6. STEM curriculum is more student-guided versus traditional curriculum which is more teacher-guided. Describe how your teaching style changed from when you taught traditional curriculum to now, as you're teaching in a STEM classroom.
7. What works the best for you as you teach STEM?
8. Describe how you measure student growth in a STEM classroom.

Best Practices & Barriers in STEM

9. Describe the barriers to teaching in a STEM classroom.
10. Describe the professional development and training resources that guided you.
11. Describe other resources that helped you as a STEM teacher
12. What do you wish you would have known when you started teaching STEM?
13. Are there any final thoughts you want to share regarding STEM?

Data Analysis

Defined as “the point at which additional data do not lead to any new emergent themes,” saturation occurred after 11 teacher interviews (Given, 2016). After the interviews were completed and recorded on Zoom, they were viewed, with responses typed word for word in an Excel sheet. Using a grounded theory approach allowed a systematic and organized process to discover the emergence of themes (Glaser & Strauss, 1967). Hand-written notes were transcribed in a notebook from the Excel sheet to visualize repeating themes. A tally mark was written by each theme as it repeated itself in the teacher’s responses. In the question “what do you like best about teaching STEM?” seeing students use the problem-solving design process was the most frequent theme. That theme came in various phrases, including “solving real-world problems” and “seeing students use the design process in action.” Teachers phrase tasks in a variety of ways, but the core concepts remain consistent and reveal themes.

Findings

The purpose of this study was to identify best practices in teaching methods, curriculum development, implementation, student outcomes, resources, and professional development within STEM education in the middle school setting. Recognizing the barriers faced by educators in employing STEM strategies is another purpose of this study.

At the beginning of the interview, demographic data were collected. All participants taught middle school (defined as grades 4 – 8), and some taught some elementary and high school classes in addition to middle school. The average number of years participants have been teachers is 19.7, with a low of 8 and a high of 25 (Figure 6). With the exception of one participant having 8 years of experience, the next most experienced teacher had 14 years of experience. Participants have been teaching STEM for an average of 8.3 years, with a low of 4 and a high of 15. Figure 7 breaks down participant's subject areas. Of the participants interviewed, 42% of participants taught science/bioscience, 17% taught agricultural education, 17% taught robotics, 8% taught art, 8% taught English/social studies, and 8% taught math.

Figure 5. Participant Demographic Data- STEM Grade Level Taught

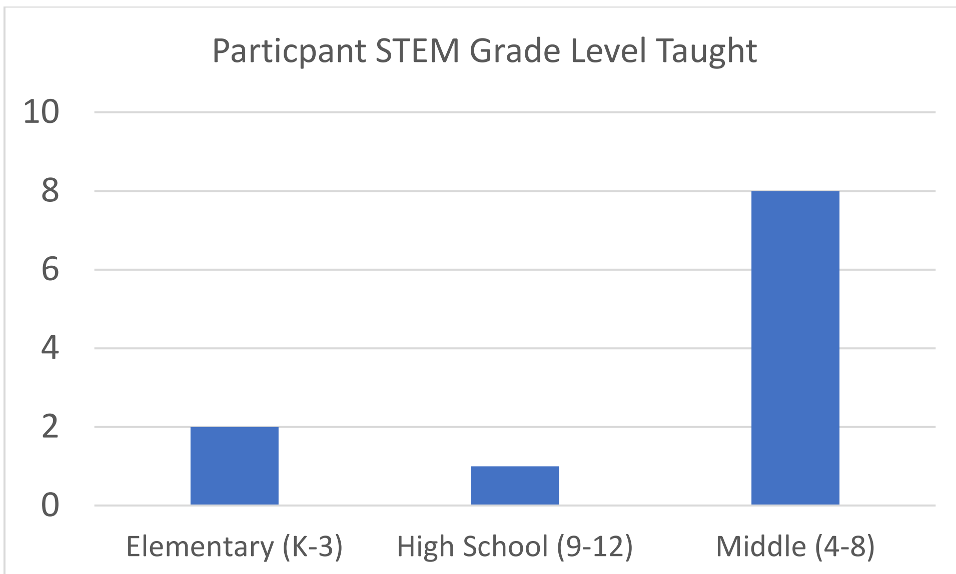


Figure 6. Participant Demographic Data- Years of Classroom Experience

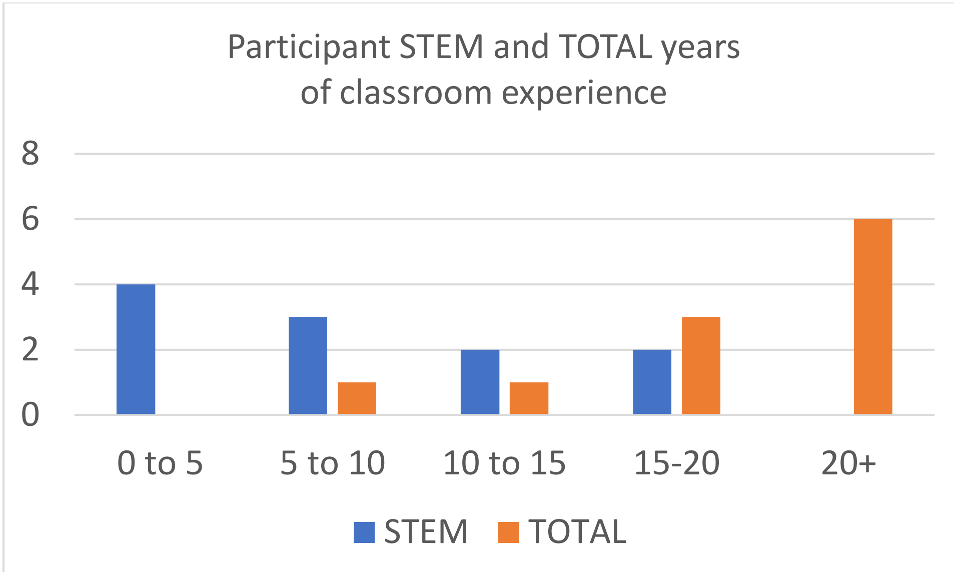
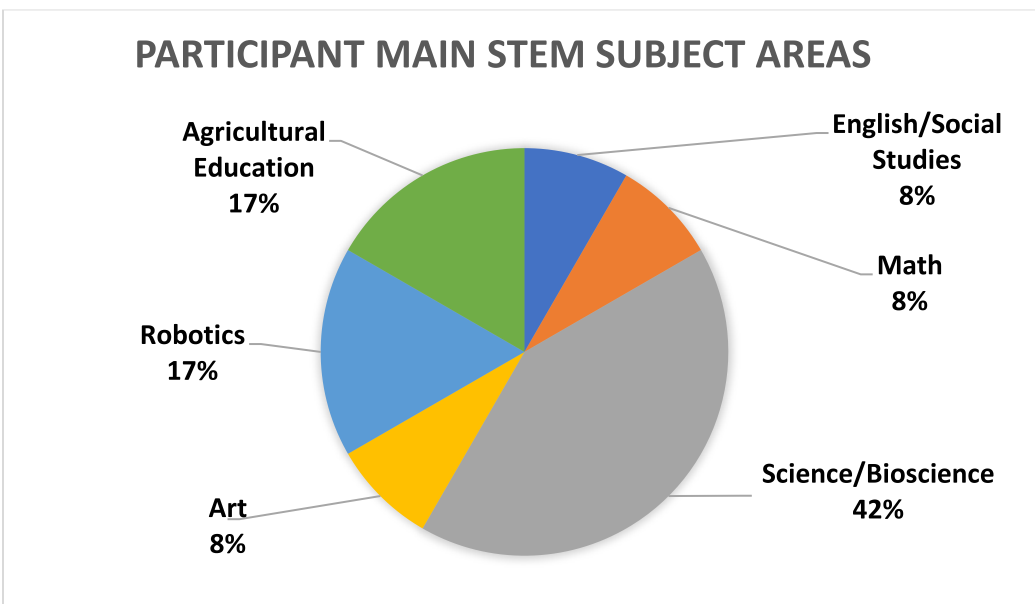


Figure 7. Participant Demographic Data- Subject Areas



Several themes emerged from semi-structured one-on-one interviews with 11 middle school STEM teachers. Themes identified were rooted in the participants own descriptions and synthesized into coding categories for analysis. 16 main themes were identified. Peer debriefing and checking to verify themes helped to establish credibility (Lincoln & Guba, 1985). Figure 9 provides the frequency with which each theme was discussed. (see Appendix B for the complete list of findings). Results are discussed by topic, focusing on the themes that were mentioned most frequently.

The top themes are: *students using the problem-solving process, teachers being flexible, students having hands-on experiences and control, grading based on the 4 C's or student presentations, and collaborate with other STEM schools for idea generation and support. Themes for barriers in STEM education are teacher's not having enough time, lack of quality curriculum, funding challenges, aligning core standards with STEM, and the support of school administration.*

Figure 9

Teacher Interview Main Themes

(11 Middle School Ohio Teachers)

What do you like best about STEM?	Responses
Seeing students use the problem-solving design process, creating solutions, failing, revising, improving, and reflecting (rewarding for teachers to experience)	5
Describe changing your classroom from traditional (teacher-guided) to STEM/project-based (student-guided.)	
Relinquish control as a teacher, be flexible, facilitate, let students be hands-on and make choices	10
Students have freedom to make choices, leading to excitement and curiosity about learning and high motivation	4
Describe how you measure student growth in a STEM classroom.	
Grade on creativity, collaboration, critical thinking, communication, and the design cycle	4
Grade through student discussions with the teacher	4
Similar to industry, student presents a summative presentation (capstone)	4
Describe the professional development and training resources that guided you.	
Visit other STEM schools to learn, collaborate, and reach out to other districts/teachers for guidance	6
Project Lead the Way professional development trainings on project-based learning	5
Describe the barriers to teaching in a STEM classroom.	
Time to create material, participate in professional development, write grants	10
Funding	7
Fitting core standards in with projects	6
Administration who does not understand or appreciate STEM and project-based learning	5

A lack of quality curriculum (teachers have to create it on their own)	4
Group work for students is a struggle	4
Too open-ended. Projects need to have an end date.	4
Allowing education to be messy, let go of control, be flexible	4

Question: What do you like best about teaching STEM?

After demographic data was discussed, participants were asked what they like best about teaching STEM. The top theme reported was seeing students use the problem-solving design process.

> "Getting kids to transition from jump through the hoops and answer the multiple-choice questions to thinking on their own is hard. It's uncomfortable" (Participant 4, personal interview, March 3, 2021).
>
> "I'm a scientist. I'm passionate about teaching kids how to think, be creative and problem solve" (Participant 10, personal interview, March 10, 2021).
>
> "STEM engages students, it gives them multiple pathways and forces them to think about thinking. Students feel uncomfortable not having things laid out for them" (Participant 9, personal interview, March 4, 2021).

Participants felt a sense of pride in their classrooms when students work on solving problems through project-based learning approaches.

Question: Describe changing your classroom from traditional (teacher-guided) to STEM/project-based (student-guided)

Discovering how teachers change their methods from a traditional (teacher-guided) focus to a project-based STEM (student-guided) focus revealed the most agreement in the study with 90% of participants stating a shared theme. Letting go of control as a teacher and being a facilitator with a flexible mindset allows the students to be hands-on and make choices as they work on a project.

> "All schools have to teach scientific methods. In my class, we do the scientific methods" (Participant 10, personal interview, March 10, 2021).

> "Understand that failure is expected, and know how to reflect on failure" (Participant 4, personal interview, March 3, 2021).
> Participants emphasized their students are learning through doing hands-on projects.

> "It's more legwork and planning, but your job as a teacher is to lay a good foundation, and have an opportunity that fits well and is planned in so they can be creative and take off from there. We call the teachers coaches because what we're doing is trying to coach students through the process. We're no longer the sole source of information" (Participant 3, personal interview, March 10, 2021).

> "When I started teaching STEM, I became more hands-off. I gave students the background knowledge and presented a problem. Then I went around to ask questions to facilitate the process" (Participant 6, personal interview, February 24, 2021).

Moving from a mindset of being an instructor to the mindset of being a facilitator is an aspect of STEM education. "Interdisciplinary approaches to STEM education require a fundamentally different instructional approach in which the teacher assumes a facilitator role of student-directed and sustained investigations for challenges" (Honey et al., 2014).

> "You have to walk away, you have to relinquish control, you can't give them the answers that would make everybody's life easier. It gets a little crazy. They're not sitting at their desks. They're not taking notes" (Participant 9, personal interview, March 4, 2021).

> "Elicit the student's curiosity, have a great relationship with them, build rapport, and allow as much buy-in, freedom and flexibility as possible with students" (Participant 7, personal interview, February 24, 2021).

> "Engaging students on a higher level is something I can never do on a worksheet. Kids are excited to learn. Finding that magic in a traditional lesson is harder. STEM opens the doors to potential" (Participant 4, personal interview, March 3, 2021). Higher level thinking is a component of STEM.

The participants descriptions of their classroom environments show the importance of a teacher's soft skills. Soft skills "include social emotional skills that facilitate positive interactions with others and the ability to overcome challenges" (Ware, 2018).

Describe how you measure student growth in a STEM classroom.

The next interview question asks to describe how teachers measure student growth in a STEM classroom. Three themes emerged. The first theme is to grade on the 4 C's: creativity, collaboration, critical thinking and communication and the design cycle. The design cycle is not part of the 4 C's, but participants added that component. Observation was used to gauge how students are progressing. Grading through reflective student discussions with the teacher is the second theme. A participant noted the importance of conversations to uncover what was learned from mistakes throughout the process, which leads to student learning and growth. They grade on the conversation of reflecting on the project journey and how their thought process changed throughout, not the end product.

> One participant commented that she "does observations and discussions with students regarding how they're working towards the goal. We do reflection as part of the design process. We ask, how did my design do, could I have built it better? We are continually going through that cycle. Look at the finished products, compare them to peers and combine ideas. This promotes the never-ending growth of STEM projects" (Participant 6, personal interview, February 24, 2021).

The last theme in the process of measuring student growth is having students present a summative presentation to either the class, teachers, or business leaders.

> "Get rid of the structured, perfect lesson plans. Have the student do a summative assessment at the end of the project by presenting a capstone, spreadsheet, video, PowerPoint, or in-person presentation" (Participant 7, personal interview, February 24, 2021).

A summative assessment will "evaluate student learning at the end of an instructional unit by comparing it against a benchmark or standard" (Kulasegaram, 2018). Summative presentations can provide legitimacy by ensuring that students have gained measurable skills from the learning experience and prepare students for their careers (Kulasegaram, 2018).

Question: Describe the professional development and training resources that guided you

Participants shared specific resources of professional development that helped them. Joining Facebook groups and blogs with teachers from other school districts with similar grade level and subject areas was a helpful tool that participants cited. Breakout Edu was a Facebook group that provided ideas and support. Another strategy was to reach out to other STEM schools to learn from as mentors through classroom shadowing and continuous communication for sharing ideas. Of the participants, five underwent the Project Lead the Way professional development training on project-based learning and noted that it was helpful.

Question: Describe the barriers to teaching in a STEM classroom

Barriers to teaching and implementing STEM in the classroom were discussed. 10 out of 11 participants cited a lack of time to prepare as the biggest barrier. Specifically, time to create materials, curriculum, write grants, collaborate with other teachers, and participate in professional development were mentioned.

> "It is hard managing time to fit standards in with projects. Project-based learning can be too open-ended." (Participant 1, personal interview, March 3, 2021).
>
> A lack of time to attend professional development and training is a barrier (Participant 8, personal interview, March 1, 2021).
>
> There is "not a lot of STEM content out there" (Participant 9, personal interview, March 4, 2021). Finding and creating content takes time.

A lack of funding is a barrier to implementing STEM. Funding includes teachers being paid for professional development hours, materials and equipment for student projects (for robotics classes, experiments, technology, etc.), the right tables and equipment to utilize classroom space for projects, and access to STEM grants. Of the participants, four worked with a combination of entrepreneurs, businesses, higher education, and government agencies for help accessing resources for project-based STEM learning.

Aligning project-based STEM learning with core standards that are mandated and tested by the state is a barrier to STEM.

> A participant posed the question "how do you implement STEM within existing curriculum?" (Participant 8, personal interview, March 1, 2021).
>
> Time comes into play again.
>
> "From a teacher's standpoint, I'm a big believer that in a core classroom (mine is science), your project-based learning has to be seamlessly aligned with your standards" (Participant 3, personal interview, March 10, 2021). This participant explained that he uses both a traditional approach to teach content and standards and then uses project-based learning to apply the concepts.

An additional barrier is *a school administration that does not understand or appreciate STEM learning.*

> "The administration needs clear cut goals with teachers. Here are the expectations. You must do one STEM project a week" (Participant 9, personal interview, March 4, 2021).
>
> A participant shared that schools "must have a supportive administration, who allows education to be messy" (Participant 4, personal interview, March 3, 2021).

"A study of over 200 teachers and administrators in the state of Illinois found that less than half understood the concept (of STEM) or could describe it" (Brown, 2012). Administrators need to understand and support STEM education.

Having access to quality professional development and training were perceived by participants as a barrier. One participant's school implemented a "train the trainer" approach where one teacher is trained in the curriculum and then comes back to their school to train their colleagues.

> "STEM learning is giving up control to the student leaner. Some teachers have trouble doing that, but they need to be willing to try" (Participant 5, personal interview, March 4, 2021).

2019 Literature Review Key Findings

A 2019 systematic literature review by Todd Kettler and Kelly Margot published in the International Journal of STEM Education analyzed 25 empirical articles from scholarly journals (published between 2000 and 2016) regarding teachers' perception of STEM integration and education. The author identified 17 key findings (see Appendix A on page 54 for the complete list of findings).

A summary of the themes includes:

- The availability of quality curriculum
- Assessment tools and planning time
- School district support, guidance, and flexibility
- The value teacher's place on STEM education
- Teacher-teacher collaboration
- Access to professional development opportunities
- Active student participation in activities within STEM education

Themes from the findings are written from the teacher's perspectives. The interdisciplinary nature of STEM is beneficial to student learning and the STEM classroom is inherently motivating to students. The struggle and failure students experience are essential and valuable components of the project-based learning process within STEM (Kettler and Margot, 2019). The teacher's efficacy beliefs and the value they place on STEM education seems to influence their willingness to engage and implement STEM curriculum (Bell, 2016). A culture of collaboration, achieved by providing time and opportunities for collaborative planning and open communication between teachers, may be critical to successful implementation (Herro & Quigley 2017). School district support, guidance, and flexibility were necessary for STEM initiatives (McMullin, & Reeve 2014). Using a project-based model of instruction facilitates success in a STEM initiative through hands-on, inquiry-based learning (Bagiati & Evangelou, 2015). A lack of knowledge of STEM disciplines, planning time, quality curriculum, and quality assessment tools are barriers to STEM initiatives (Nadelson & Seifert, 2013). Well-organized and frequently available professional development opportunities would facilitate successful STEM initiatives (Nadelson & Seifert, 2013).

Overlapping Themes

The 2019 systematic literature review key findings from teacher's perspectives are combined with this study's themes to identify overlapping themes in STEM education. Figure 8 identifies these overlapping themes in a chart. Of the author's 17 key findings, 7 themes overlap this study (see Appendix A for the complete list of findings). This study's findings from eleven teacher interviews are aligning with the broader 2019 literature review of teacher's perceptions. The consistencies in teacher's perceptions of barriers and best practices in STEM classrooms across this study and the literature review suggest key overlapping themes that should be emphasized for school districts moving into a STEM teaching model.

Figure 8. Overlapping Themes from this study and a 2019 Systematic Literature Review

This Study's Themes (From teachers' point of view)	Key Findings from 2019 Systematic Literature Review
Characteristics of STEM Education	(Margot & Kettler, 2019)
Students have freedom to make choices, leading to excitement and curiosity about learning with high motivation	Teachers believe STEM education is inherently motivating to students.
Students create solutions, fail, revise, improve, and reflect using the problem-solving design process (rewarding for teachers to experience)	Teachers believe that struggle and even failure are inherent yet valuable components of the engineering design process within STEM.
Visit other STEM schools to learn, collaborate, and reach out to other districts/teachers for guidance	Teachers believe that a culture of collaboration would increase the viability of STEM programs.
Professional development trainings on project-based learning are important	Teachers believe that well-organized and frequently available professional learning opportunities would facilitate successful STEM.
Barriers	
Administration who does not understand or appreciate STEM and project-based learning	Teachers perceived typical school structures are barriers to the implementation of STEM education. Teachers perceive school district support, guidance, and flexibility were necessary for STEM initiatives.
A lack of time exists to create material, participate in professional development, write grants	Teachers perceive that lack of quality assessment tools, planning time, & knowledge of STEM disciplines are challenges & barriers to STEM.
A lack of quality curriculum (teachers have to create it on their own)	Some teachers, especially at the high school level, perceive the integrated nature of STEM curriculum is a challenge. Teachers believe that the availability of a quality curriculum would enhance the likelihood of success of STEM initiatives.

Discussion Regarding Overlapping Themes

Of the 7 overlapping themes detailed in figure 8, the two most common themes centered around a lack of quality curriculum and the time intensive nature of creating STEM programs. From the 2019 systematic literature review, the finding that "teachers believe that the availability of a quality curriculum would enhance the likelihood of success of STEM initiatives" aligns with sentiments in the 11 teacher interviews. "Not having a set curriculum is a barrier. Time to create the material is a barrier" (Participant 1, personal interview, March 3, 2021). The struggle to teach content to the state's standards for testing, a wide variety of student ability levels, the open-ended nature of project-based learning, students working effectively or ineffectively in groups, and having adequate planning and instructional time were the largest hurdles gleaned from the interviews. If a standard, quality STEM curriculum was created, it may alleviate the pressure on teachers to create quality curriculum from scratch with limited time. A standard curriculum could help rope in the open-ended nature of STEM and provide a framework to work from.

Throughout the teacher interviews, collaboration with other teachers within their school (for example, the 5th grade English teacher working closely with the 5th grade science teacher) and working with teachers in other districts (shadowing and sharing ideas) was cited as the most effective resource for learning. Of the participants, five mentioned utilizing specialized Facebook pages or blogs to pose a question they were seeking guidance on. This practice provided real-time feedback and sharing of ideas to improve teaching methods. The 2019 literature review found that "teachers explained the importance of collaborating with other STEM teachers and university professionals in order to not only create an atmosphere that enhances preparation for STEM lessons, but also to model a team approach to students" (Margot & Kettler, 2019). Another participant said they use other teachers as sounding boards.

Collaboration also extends to tapping into the expertise in community businesses as strong resource partners.

"Students are asked to improve upon their designs and solutions. They are encouraged to take risks" (Margot & Kettler, 2019). When teachers were asked what they like best about teaching STEM, the most frequent answer was seeing the problem-solving design process in action. "Design thinking can relate to the way that you write, produce art, create music, use technology, understand science; it's a large umbrella that embodies a lot of different learning" (Participant 3, personal interview, March 10, 2021). "Failure is expected, learn how to reflect on failure" (Participant 4, personal interview, March 3, 2021). In STEM education, students create solutions, fail, revise, improve, and reflect using the problem-solving design process. Teachers feel this is beneficial to students, especially high-achieving students that typically do not reach a point of frustration in their classrooms (Dare et al., 2014). "Because failure is part of the process, it is expected and therefore accepted. This encourages students to do things they do not know how to do and challenge themselves to confront failure" (Margot & Kettler, 2019). As teachers relinquish control and facilitate with a flexible mindset, students can be hands-on and free to make choices and grow in their learning. Experiencing and dealing with failure leads to student resiliency and confidence with the teacher guiding the process. These experiences prepare students for more challenging higher education curriculum and future work situations.

How do teachers walk this fine line between providing enough content knowledge and structure in their classroom to turning over control to allow students to collaborate together and create solutions? The answer lies in the nuanced details of embracing the project-based learning model. To gain clarity of how to effectively run a project-based learning classroom, teachers need effective professional development. An overlapping theme is the need for well-organized and frequently available professional development opportunities for teachers (Margot & Kettler, 2019). “I don't see a conscious effort of schools providing STEM-oriented training. I’ve had to find my own STEM content and concepts” (Participant 9, personal interview, March 4, 2021). Professional development could help teachers put a framework together on combining content standards with project-based learning. This is hard work. Having the support and confidence of professional development can give teachers tools to be effective and prevent them from reinventing the wheel.

Discussion Regarding This Study

The following objectives posed to middle school teachers drove this study:

1. Identify the resources and barriers to creating and implementing STEM curriculum in middle schools in Ohio.
2. Explain how a project-based STEM model has the potential to increase student’s critical thinking skills and improve student outcomes.
3. Define why STEM curriculum is important in today’s middle school educational environment.
4. Describe how student growth is measured in a project-based STEM classroom.

Resources and barriers to creating and implementing STEM

As a portrait of STEM education in Ohio, this current research focused on teacher’s perceptions of STEM education through a variety of lenses. The first lens is through the teacher’s pedagogical approach. Professional development and training on project-based learning and interdisciplinary teaching are imperative to success for STEM teachers. The administration’s values and support of STEM education are vital to supporting teachers and students in the student-centered, often messy process of STEM. Mentorship and sharing of ideas in the form of online blogs, groups, and communication with neighboring districts is a valuable resource for teachers to tap into.

The second lens is through the supports that school districts receive. Non profits such as Project Lead the Way can provide curriculum, training, and guidance for school districts looking to enact STEM. Parents of students should be supportive of grading based on mastery, presentations, and student/teacher discussions to assess student growth and outcomes. Teachers must support each other and their students as they go through the hard work of turning the reins over to students to be in control of their own learning. It is a fine balancing act of creating a classroom environment conducive to project-based learning. By setting a framework with problems to solve, the teacher can interact as a coach and facilitator while students create, fail, create again, and continually revise solutions to problems. Critical thinking skills and self-efficacy can grow and evolve in students in this atmosphere. Local businesses and higher education can influence STEM classrooms by providing content, materials, funding, access, and expertise to connect students to real-world issues. Legislation on the state and national levels affects the ability of schools to potentially receive grants to move into a STEM teaching environment.

Looking through a third lens, teachers describe what holds school districts back from achieving effective STEM programming. Challenges facing STEM education are plentiful. The lack of a common language to describe STEM creates confusion. Project-based learning, problem-based learning, PBL for short, experiential learning, or the engineering design process? Interdisciplinary, cross-curricular, or integrated STEM? Many terms have similar meanings, but this lack of a common, consistent language creates a barrier to understanding in many stakeholders. Teachers and administrators need to be willing and open to change with flexibility in mind as they transform their classrooms from a traditional approach to a STEM approach. A lack of time for lesson planning and a lack of resources in the forms of funding and facilities is another barrier. Students present their own challenges to enacting STEM. Being able to teach to all ability levels in a classroom along with students having short attention spans and a lack of cooperation in group work create further barriers. Teaching to content standards and state testing while simultaneously fitting in project-based learning is a barrier. Professional development needs to be easily accessible, frequent, and effective to support teachers.

A project-based STEM model may improve student outcomes

Students in a project-based learning STEM classroom will work to answer problems using the problem-solving design process. The participants shared that through this design process, students are presented with a problem and create solutions, fail, revise their solutions, improve, and reflect on the experience. This process mimics how professionals solve real problems in business, offering experience to students to flex these important problem-solving muscles for a brighter future. Students gain a deeper understanding of subject content by constructing their own knowledge and through reflecting on the learning cycle (Holmlund, et al, 2018). Participants reported that engrossing students in active, higher level learning is a key reason why they prefer STEM classrooms to traditional classrooms. Engaging students in critical thinking is achieved in the project-based model and is a key skill for the student's future higher education and career opportunities.

Why STEM curriculum is important in the middle school setting

The journey to increase the number of STEM-designated schools in Ohio is a worthwhile endeavor. Our country is changing the way we do business daily due to society's evolving needs, research, and technological advances. Equipping today's K-12 students with 21st century knowledge and skills like critical thinking, problem-solving, creativity, collaboration, communication, curiosity, decision making, acceptance of failure, and leadership skills is imperative to our country's success. STEM education employed through a project-based learning model provides hands-on opportunities for students to work at the aforementioned skills in a supportive classroom environment. The middle school has a unique opportunity to give students a leg up through providing problem-solving STEM experiences that prepare them for high school. These skills can move with the student to higher education and into their careers where they can make an impact.

Research has shown that the need for STEM skills in the 21st century is evident. Funding and interest continue to grow in STEM education. As teachers are trained in STEM pedagogy and access to effective project-based curriculum increases, Ohio will transition into more STEM-designated schools. The critical thinking skills and strong student outcomes support the push for more STEM education now and into the future.

Measurement of student growth in the STEM classroom

A challenge in STEM classrooms that does not exist as starkly in traditional classrooms is the question of how to measure student growth. With open-ended solutions to problems and a student-centered approach, participants gave insight into their methods of student assessment. By breaking down and grading the student's projects based on the 4 C's: creativity, collaboration, critical thinking and communication, this rubric provides a comprehensive view of the student's approach to problem solving. A more interactive and ongoing discussion regarding projects between teacher and student exists in STEM classrooms. These discussions allow for deeper understandings into the student's thought process. Utilizing summative presentations at the end of a project is another method to assess student's growth and content knowledge. This experience helps prepare students for presentations in their future academic and career settings.

Students can create written or recorded reflections to share with peers and/or the teacher to gauge their progress and learning. Assessing the student's project based 50% on accuracy and content and 50% on problem-solving style and creativity is another approach to grading projects.

Recommendations

Professional Development Strategies

The following recommendations can be shared with McCormick Middle school as they move through the process of STEM-designation from the Ohio Department of Education. Create an effective program for initial and ongoing STEM professional development for teachers. The administration can take the burden off the teachers by selecting, scheduling, and coordinating recurring, high quality professional development trainings. Tap into the knowledge of current STEM teachers in surrounding school districts through continuous communication and support systems. Collaborating with current STEM teachers is a best practice that can provide new STEM teachers with the support and confidence to forge ahead on this new path with guidance. One strategy to accomplish this is through teachers and administrators touring and shadowing other STEM school districts to immerse themselves in the STEM culture and environment. By tapping into community businesses and higher education resources, schools can unlock a wealth of opportunities, content, problems to solve, funding, and professional experts in STEM that can enhance teacher's efforts.

The role of Project Lead the Way

Utilize quality STEM curriculum and training from the non-profit Project Lead the Way. The barriers teachers mentioned including a lack of time, quality curriculum, and effective training can be solved by working with Project Lead the Way on teacher professional development and curriculum. Project Lead the Way is nationwide and delivers curriculum to

12,200 schools and STEM professional development with over 77,500 teachers trained to date (Project Lead the Way, 2021). Started in 1997 as a high school engineering program, Project Lead the Way now services students in grades PreK-12 with STEM curriculum pathways in computer science, engineering, and biomedical science (Project Lead the Way, 2021). McCormick Middle school is working with Project Lead the Way STEM curriculum with plans to implement it during the fall 2021 academic year.

School Culture

School culture is vital to the success of STEM. The administration can set and maintain the cultural tone that teachers, students, parents, and the community support. When change in an organization occurs, resistance and fear may accompany that change. A key component to reducing resistance can include creating a consistent vision and culture within the school that supports change and encourages teacher and student growth while learning together. The need to embrace the uncertainty and open-ended nature of STEM classrooms is necessary to lay the foundation for potential success in STEM education. STEM requires interdisciplinary collaboration of teachers within the school district and grade levels. The principal can encourage and sell the process of teachers working together collaboratively for the benefit of the students in connecting content and subject areas. Achieving this takes intentional work and teacher training on collaborative learning. The hard work of developing students as critical thinkers who are equipped to handle the challenges of the 21st century is a meaningful undertaking. This can be accomplished by exhibiting strong administrative leadership with a school culture that is supportive and focused on continuous growth and improvement.

Student Outcome Assessments

Administration can recognize the lack of time available to teachers and devise a feasible solution to reduce time constraints within the teacher's work day. Building a cohesive plan to assess and grade student's mastery of content that is consistent across all grade levels is important. Project Lead the Way has student assessment tools and rubrics to accomplish this non-traditional grading style. One of the main takeaways from this paper is to remain flexible and adaptive as schools' transition into STEM classrooms. Just as project-based learning is a continual process of creating, failing, and revising, the same principles apply to school districts embarking on this important educational journey. With continuous improvement, an intentional focus, and hard work, middle schools can be a launching pad for innovation in STEM education.

STEM education in the K-12 and collegiate settings will continue to be emphasized moving into the future. Further research recommended includes creating a common language around STEM, studying the higher education and career outcomes of students in their mid to late 20's who attended STEM schools during their K-12 education, studying the effectiveness of various professional development techniques within STEM, and understanding the various ways student assessment in STEM classrooms is accomplished.

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Appendix A

Teachers' Perception of STEM Integration & Education Key Findings

1. Teachers' years of experience are inconsistently related to their perceptions of STEM integration or education, and teachers' value or interest in STEM may mediate the relationship.
2. Age, gender, and STEM experiences of teachers may also play a role in their perceptions of STEM education.
3. Teachers emphasize the importance of student participation in application activities within STEM education as a crucial indicator of their academic achievement.
4. Teachers perceive that the cross-curricular nature of STEM education is beneficial to student learning, but secondary teachers may perceive barriers or challenges to cross-curricular programs.
5. Teachers believe STEM education is inherently motivating to students.
6. Teachers believe that struggle and even failure are inherent yet valuable components of the engineering design process within STEM education.
7. Teachers' efficacy beliefs and the value they place on STEM education seems to influence their willingness to engage and implement STEM curriculum.
8. Teachers perceive that STEM pedagogy requires some fundamental shifts in how they establish classroom environments and teach, and for some teachers these shifts are not always positive.
9. Some teachers, especially at the high school level, perceive the integrated nature of STEM curriculum is a challenge.
10. Teachers perceived typical school structures are barriers to the implementation of STEM education.
11. Teachers believe that students are unable or unwilling to be successful with STEM education or initiatives.
12. Teachers perceive that lack of quality assessment tools, planning time, and knowledge of STEM disciplines are challenges and barriers to STEM initiatives.
13. Teachers believe that a culture of collaboration would increase the viability of STEM programs.
14. Teachers believe that the availability of a quality curriculum would enhance the likelihood of success of STEM initiatives.
15. Teachers perceive school district support, guidance, and flexibility were necessary for STEM initiatives.
16. Teachers perceive that previous experience using student-centered, inquiry models of instruction facilitate success in a STEM initiative.
17. Teachers believe that well-organized and frequently available professional learning opportunities would facilitate successful STEM initiatives (Margot & Kettler, 2019).

Appendix B

Teacher Interview Complete Responses
11 Middle School Ohio Teachers

What do you like best about STEM?	Responses
Seeing students use the problem-solving design process (students create solutions, fail, revise, improve & reflect)	5
Exposing students to the constructivist learning process (students being uncomfortable, not knowing the answer, constructing knowledge)	3
Students taking ownership of their work (student-centered learning)	3
Using project-based learning as the teaching mode	2
Solving real-world problems	2
The open-ended nature of STEM solutions	2
Teacher's ability to be creative with curriculum	2
Getting students to think outside of the box	2
Engaging students in critical thinking	2

Describe changing your classroom from traditional (teacher-guided) to STEM/project-based (student-guided.)	
Relinquish control as a teacher, be flexible, facilitate, let students be hands-on	10
Students have freedom to make choices, leading to excitement and curiosity about learning	4
Project-based learning must align to content standards	1
Engaging in active, higher level learning (versus passive learning)	1
Using a guided-inquiry approach, students make choices along the way	1
Classroom environment is controlled chaos	1
Scaffold lessons, prepare students with solid content foundation before starting project-based learning	1

What works the best for you as you teach STEM?	
Be open to colleagues' ideas	2
Do not reuse the same project	1
Let students direct the questions	1
Look for connections and make it meaningful	1
Do activities with speed	1
Failure is expected, learn how to reflect on failure	1
Lean how to apply the content	1
Embrace a mindset that is comfortable with structured chaos	1
Give students a challenge	1

Describe how you measure student growth in a STEM classroom.	
Grade on creativity, collaboration, critical thinking, communication, and the design cycle	4
Grade through reflective student discussions with the teacher	4
Similar to industry, student provides a summative presentation (capstone)	4
Have a strong rubric to start with, determine what mastery looks like	2
Utilize reflection as part of the design process	2
Measure student success on half accuracy & content, half problem-solving and creativity	1

Describe the professional development and training resources that guided you.	
Visit other STEM schools to learn, collaborate, and reach out to other districts/teachers for guidance	6
Project Lead the Way professional development trainings on project-based learning	5
Use Edpuzzle project-based learning worksheet for lesson plans	1
Plan for the first, middle, and end blocks of class, change it up to prevent stagnation	1
Use the OSU Extension office resources	1
Define student's roles in the project (gives a framework)	1
Use the “PBL you are great” training	1
Use the Buck Institute PBL learning training	1
Take PBL 101 through www.bei.org	1
Take PBL Spring through Otterbein College	1
Take the OSU Straight A grant for teacher training	1
Utilize a "train the trainer" model within districts	1
Take the PBL course from Jody Haney at Bowling Green State University	1
Read good STEM books	1
Teachers need to be trained to help kids "learn on the fly"	1

Describe the barriers to teaching in a STEM classroom.	
Time to create material, participate in professional development, write grants	10
Funding	7
Fitting core standards in with STEM projects	6
Administration who doesn't understand/appreciate STEM and project-based learning	5
Not having enough curriculum (having to create it on your own)	4
Group work for students is a struggle	4
Too open-ended. Projects need to have structure and an end date	4
Allowing education to be messy, let go of control, be flexible	4
Student's short attention spans	3
Individual building barriers (not enough classroom space)	3
Understand that failure is expected, learn to reflect on failure	3
The school shoots down teacher's ideas	2
Teaching students with variation in ability levels	2
STEM is not a core course (only offered as an elective), can get cut	2

Monitoring progress in projects	2
Students cooperating with each other (this skill has dwindled)	1
Not enough conscious effort towards teacher professional development	1
Student's loss of interest in subject matter	1
Teacher's willingness to try new things	1

What do you wish you would have known when you started teaching STEM?

It's the way to teach	3
STEM is messy, it will veer	3
Students learn by doing	3
Don't get caught up on the letters, adding engineering & technology gives them 21st century skills	2
It's okay to make a mistake, be willing to fail as a teacher	2
Embrace the STEM philosophy of creativity & letting students construct their own knowledge	2
Teacher undergoes continuous growth & revisions	1
I wish I had the mindset early on of: Don't be afraid to try something knowing that some students aren't going to get there	1