From the Editor

As the world moves forward while attempting to find relief from the debilitating effects of the global SARS-CoV-2 (Covid 19) pandemic, PK-12 schools, STEM institutions, organizations, researchers, higher education departments, and informal education programs are still trying to visualize what the "new educational order" will look like and from those perspectives rethink or even rewrite their strategic plans and curricula. We are seeing the emergence of a "new" type of educational experience for students world-wide that includes connections to real world problems on an everyday basis, which is exactly what STEM education presupposes, particularly in problem-solving, including engineering design. It is unfortunate that it took a global emergency to make this change, which is long overdue.

The *Southeast Asian Journal of STEM Education's* parent organization, Southeast Asia Ministers of Education Organization (SEAMEO) Regional STEM Education Centre (STEM ED) is engaged in an evolving strategy of designing and offering face-to-face, digital, and hybrid projects, workshops, and conferences. The SAJSE is also changing, not only in its reach, but also in its design. Within another month, the journal will take on a new, and we think more attractive look. We welcome your comments.

This issue contains articles by authors from around the world, who are--or have been--involved in exciting STEM research studies and projects. We are pleased to showcase them on the following pages.

Edward M. Reeve analyzes the current state of the world in light of the pandemic and argues in his article the crisis demands that STEM be at the center of every school's curriculum in order to deal with *real* world problems. **Apichart Intha and Kongkiti Phusavat** describe an exciting outdoor STEM project for underprivileged students in a Bangkok school that not only solved a major health issue but also created an income source for the students. Their article is inspiring, in that it shows that students who are often overlooked because they are not college-bound, can create STEM-based small businesses that are also Earth-friendly. Another exciting project, in which a university and a local school district joined forces to create a STEAM school in the U.S. is described by **Bhaskar Upadhyay, John Alberts, Kara Coffino, and Andrew Rummel.** Mathematics educators **Thierry Dana-Picard, Sara Hershkovitz, Zsolt Lavicza, and Krístof Fenyvesi** analyze the "golden section" ratio, present examples of where it has been used in architecture, the locations of ancient structures on Earth's "great circles," and even in calendars; they give suggestions for engaging students in studying the golden section using the popular online app GeoGebra. **Jeff Weld,** who was senior White House advisor for the U.S. five-year STEM Education strategic plan, shares his views on the process of this important endeavor, and how it will positively impact *all* students, particularly those who are skilled in STEM fields but who are not university-bound. The article is reprinted by permission from CADRE (Community for Advancing Discovery Research in Education).

My thanks go to the authors and also to the reviewers and proofreaders who, as always, helped make this issue one of high quality. Seeing the final formats in an issue does not show the countless hours and often weeks of revisions that go into each article through conversations between the authors, the editor, and the reviewers. I hope you enjoy the articles. We welcome your comments. I wish you a very peaceful, productive, and SAFE 2021!

John Stiles, Editor in Chief

The Need for STEM Education: Now More Than Ever!

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Abstract

Science, Technology, Engineering, and Mathematics, or STEM, are a part of all our lives and impact us daily. STEM education provides an opportunity to integrate two or more of the disciplines, which often leads to better student motivation and understanding of the materials being covered. Teachers at all grade levels who teach some aspects of STEM in their lessons are encouraged to add this teaching and learning approach into their classrooms. This article briefly discusses the components of STEM and STEM education and reviews important reasons for teaching about STEM. These important reasons note that STEM education is needed for global competitiveness, that it is involved in almost everything in our lives, and that STEM professionals working together will be needed to solve global problems.

Keywords: STEM, STEM education, global competitiveness, global problems, STEM standards, problem-solving, scientific inquiry, engineering design.

In May 2020, history was made in the United States (U.S.) as the National Aeronautics and Space Administration (NASA) teamed up with Space Exploration Technologies Corporation (known as *SpaceX)* to launch two Americans into space. SpaceX is a private American aerospace manufacturer and provided the equipment to launch Americans into space from American soil.

The purpose of this launch was to send American astronauts to the international space station (ISS). It was the first time in nearly a decade that Americans were launched into space from American soil. Previous to this launch, American astronauts were ferried to the ISS on Russian-made space rockets (i.e., Soyuz) (Kelly & Shannon, 2020). In early August 2020, the two NASA astronauts successfully splashed down in the Gulf of Mexico (Aerotech News, 2020).

In early 2020, the COVID-19 virus (i.e., *coronavirus disease,* [SARS-CoV-2]) became a pandemic that threatened global health. At the time of this writing (21 December 2020), there have been more than 17,000,000 cases in the U.S., more than 300,000 people have died from this virus, and the numbers continue to grow alarmingly. Globally, more than 1,600,000 people have died and there have been more than 76,000,000 cases (Johns Hopkins University, 2020). The virus has created a "new normal" around the world that consists of such practices as social distancing, frequently washing one's hands, and wearing face masks. Currently vaccines by Pfizer and Moderna have been approved and are being distributed in limited numbers. Vaccinations have begun in other countries as well, including the United Kingdom and Germany. However, there are still more than 50 vaccines being tested by research professionals from around the world are working to find one as this virus has impacted lives around the globe (World Health Organization, 2020).

The two different events discussed above have one thing in common, they have demonstrated the need for Science, Technology, Engineering, and Mathematics or STEM professionals to work together. As Bybee (2018) notes in his discussion on 21st Century challenges (e.g., climate change, clean water, the vulnerability of the Internet, and energy efficiency), people seeking solutions to these problems will look at least somewhat to STEM (p. 6).

STEM is a part of all of our lives and impacts us on daily basis. It impacts our food, our transportation, our housing, and how we communicate. For example, a plastic bottle of drinking water has been influenced by each of the disciplines of STEM. *Science* has been involved in purifying the water and its taste. The bottle and cap are results of *technology. Engineering* has been involved in making the machines to fill, cap, and label the bottles. *Mathematics* has been involved in calculating the diameter of the bottle, its thickness, and the amount of liquid it will hold. However, in the water drinking water bottle example, STEM has not worked in isolation; it has required that professionals from all disciplines work together in such areas as design and safety to produce a product (i.e., bottled water) to meet consumer needs and wants. Today, students need to learn about STEM more than ever.

Why STEM Education?

The need for STEM education may best be summarized by the National Science Foundation, which in 2007 noted:

> In the 21st century, scientific and technological innovations have become increasingly important as we face the benefits and challenges of both globalization and a knowledge-based economy. To succeed in this new information-based and highly technological society, all students need to develop their capabilities in STEM to levels much beyond what was considered acceptable in the past (p. 2).

In the U.S., STEM education is promoted by many states and government organizations. For example, the U.S. Department of Education (n.d.) notes:

> In an ever-changing, increasingly complex world, it's more important than ever that our nation's youth are prepared to bring knowledge and skills to solve problems, make sense of information, and know-how to gather and evaluate evidence to make decisions and these are the kinds of skills that students develop in STEM. (para. 1)

The need for all students (i.e., Primary – Grade 12) to learn about STEM in their studies is now more important than ever. The author suggests that the three main reasons today why all students should learn about STEM are the following:

- It is needed for global competitiveness.

- It is involved in almost everything in our lives.
- It is needed to solve global problems.

This article will review each of these in more detail below. However, before examining these reasons, the author will provide a brief review of STEM education, including how it is defined, its components, content standards, and its benefits.

What is STEM Education?

STEM education has been defined in many contexts. However, it typically refers to teaching the components of STEM in an integrated manner, which may help students better learn the topic being presented. It is about teaching the content, practices, and processes that STEM uses to meet human needs and wants and to solve real-world problems. STEM can be taught in most subject areas, but it is perhaps best taught in one of the areas (e.g., science or technology and engineering education) where teachers have had specific training in one or more of the STEM disciplines. Regardless of what level it is taught, STEM education may require teachers to learn (e.g., through professional development) new concepts, content, or practices that may be "outside their area of expertise."

The *Southeast Asian Ministers of Education Organization* (SEAMEO) STEM-ED Center (SEAMEO STEM-ED, n.d.a) provides a good definition of STEM education as:

> a teaching and learning approach, which emphasizes the connections among – or the integration of – knowledge and skills in science, technology, engineering, and mathematics (STEM) to address problems facing our communities as well as larger global issues that require a skilled workforce and knowledgeable citizens who can apply these skills and knowledge to develop solutions. (para. 1)

The *International Technology and Engineering Educators Association* (ITEEA) is a professional organization for technology, innovation, design, and engineering educators. They define what they identify as *Integrative STEM Education* (ITEEA, n.d.). In their definition, they have operationally defined Integrative STEM Education as:

> the application of technological/engineering design-based pedagogical approaches to intentionally teach content and practices of science and mathematics education through the content and practices of technology/engineering education. Integrative STEM Education is equally applicable at the natural intersections of learning within the continuum of content areas, educational environments, and academic levels (Wells & Ernst, 2012/2015), (as adapted from Wells/Sanders program documents 2006-10). (para. 1)

In addition to STEM education, the literature may mention the need for STEAM education (i.e., adding the arts to STEM) or even the need for STREAM education where the "R" may refer to Reading, "wRiting," or Research. The author contends that all of these (i.e., the arts, reading, writing, and research) are important, but that they are all inherent in STEM Education. For example, when designing a consumer product, the designers and engineers will not only make sure it functions correctly but that it is aesthetically pleasing (i.e., following good art and design principles).

Effectively teaching STEM Education begins with a good understanding of the components of STEM. The ITEEA *Standards for Technological and Engineering Literacy - STEL* (ITEEA, 2020, p. 21) describes them as follows:

> **Science** involves the investigation and understanding of the natural world.
>
> **Technology** is the modification of the natural environment through human-designed products, systems, and processes to satisfy needs and wants.
>
> **Engineering** is the use of scientific principles and mathematical reasoning to optimize technologies in order to meet needs that have been defined by criteria under constraints. (*Engineers create technology!* - Author added).
>
> **Mathematics** enables communication and critical analysis and how we make sense of the human and natural world using numbers and computational reasoning.

STEM education is not a class, it is a culture that instructors build in their classrooms. It is an integral part of today's jobs and past jobs (Wood, 2020). The National Science Teaching Association (NSTA, n.d.) takes a position that it is "an experiential learning pedagogy in which the application of knowledge and skills are integrated through in-context projects or problems focused on learning outcomes tied to the development of important college and career readiness proficiencies" (para. 1).

STEM education is a teaching and learning approach that presents students with real-world problems and challenges to solve. It is student-centered learning where instructors serve as mentors to help guide students in finding solutions to their problems or answers to their questions. STEM education helps develop analytical skills in students. Doyle (2020) notes that analytical skills "refer to the ability to collect and analyze information, problem-solve, and make decisions" (para. 1).

In the U.S., there is no national curriculum and each state typically has a department of education that directs the curriculum offerings. However, most states recognize the importance of STEM in their states and more than half of them have developed websites that provide resources to support STEM education (e.g., see https://www.pta.org/docs/default-source/files/programs/stem/2017/math-night-toolkit/stem-families-resources-stem-by-state.pdf).

Although there is no national curriculum in the U.S., professional organizations and associations have developed international or national standards that identify the content to teach. Today most states will review these standards as they develop curriculum offerings for their state. The content to teach in these STEM standards can be freely accessed on the Internet. National/International content STEM standards include the following:

- **Science.** *Next Generation Science Standards (NGSS)*: https://www.nextgenscience.org
- **Technology and Engineering.** ITEEA *Standards for Technological and Engineering Literacy: Defining the Role of Technology and Engineering in STEM Education (STEL)*: https://www.iteea.org/stel.aspx
- **Mathematics.** *Common Core State Standards Initiative*: http://www.corestandards.org/Math

Moving STEM education forward will require a strong collaboration of those involved. Recently major national/international organizations involved in STEM education (i.e., Advance CTE, the Association of State Supervisors of Mathematics, the Council of State Science Supervisors, and the International Technology and Engineering Educators Association) published a joint document entitled *STEM^4: The power of collaboration for change* (n.d.). In this document, they identified three main principles to drive and implement outstanding STEM education research and practices. To help move STEM education forward in P-12 education, these principles provide stakeholders with sound advice to follow. The three main principles noted in the report to drive STEM education include Principle 1: STEM education should advance the learning of each individual STEM discipline, Principle 2: STEM education should provide logical and authentic connections between and across the individual STEM disciplines, and Principle 3: STEM education should serve as a bridge to STEM careers (p. 3).

Scientific Inquiry and Engineering Design

Important in the teaching of STEM education are the practices associated with scientific inquiry and engineering design that provide students with investigative hands-on learning experiences. Students learn best “by doing” and when they engage in scientific inquiry and engineering design, they are often better motivated to learn the materials being presented and gain a deeper understanding of how STEM is integrated. Well-designed STEM education activities promote doing, problem-solving, and using 21st Century skills such as the 4C’s (i.e., critical thinking, communication, collaboration, and creativity) that have been promoted by P21’s Frameworks for 21st Century Learning (Battelle for Kids, 2019), among others. They can also be used to promote empathy, systems thinking, and teaching students about the global world they live in (Kaiser, 2020).

Engineering design and science inquiry share several similar features, but there are some differences, especially when considering the constraints related to solving the question asked (science) or problem presented (engineering), (LinkEngineering, n.d.). As Sneider (2015) notes, “if they are trying to answer a question, they are doing science. If they are trying to solve a problem, they are doing engineering” (p. 3). However, both engineering design and scientific inquiry promote student learning of key analytical skills such as doing research and analyzing data. Shown in Figure 1 is a comparison of the practices of engineering design and scientific Inquiry

Scientific Inquiry in the most basic sense involves asking questions about how something works in the natural world and collecting evidence to propose explanations related to the experience (e.g., finding out at what temperature water boils at different elevation levels). Important in scientific inquiry is the collection, analysis, and interpretation of data. Teachers who use scientific inquiry in the classroom present students with scientific questions that spark their curiosity and creativity to find answers related to natural phenomena using scientific practices (e.g., scientific methodology) (National Research Council, 2000).

Engineering design is a problem-solving approach to solve real-world problems and challenges presented to students. Scientists investigate the natural world and engineers create technology. There are many engineering design process models, but most involve similar steps that require students to define and research the problem, propose solutions to the problem, build and test prototypes related to the problem and present their solutions. When teachers present engineering design challenges to students, they let them know that it is all right to fail and that there are typically many different solutions to the problem presented.

Figure 1

Comparing the Practices of Engineering Design and Scientific Inquiry

Practice *Engineering Design*	**Practice** *Scientific Inquiry*
Focus: Identifying and solving problems in the real-world; Developing/creating new products, processes, and systems.	Focus: Asking questions in the natural world; Developing new theories; Explaining phenomena.
Research: Collecting research data related to the problem or challenge.	Research: Collecting research data related to the observed phenomenon.
Working under criteria and constraints.	Working under the laws of nature.
Proposing solutions; Building a model or prototype;	Proposing explanations; Testing a hypothesis; Performing an experiment under controlled conditions
Collecting and analyzing data; Testing and redesign as needed.	Collecting and analyzing data.
Sharing results (e.g., the prototype).	Sharing results (e.g., drawing a conclusion).

The author agrees with Jolly (2017) who notes that “STEM develops a set of thinking, reasoning, teamwork, investigative, and creative skills that students can use in all areas of their lives” (paras. 5-9). She also provides six characteristics of great STEM lessons that should be considered as instructors develop STEM curricula and learning experiences. These characteristics note that STEM lessons:

- should focus on real-world issues and problems;
- are guided by the engineering design process;
- immerse students in hands-on inquiry and open-ended exploration;
- involve students in productive teamwork;
- apply rigorous math and science content the students are learning;
- allow for multiple right answers and reframe failure as a necessary part of learning.

She further notes that an online search of "STEM lessons" will yield plenty of results. Today there are many examples of websites that provide good STEM lessons. Here is a sampling: Teach Engineering (https://www.teachengineering.org), Design Squad (https://pbskids.org/designsquad), NASA's Beginning Engineering, Science and Technology (https://www.nasa.gov/audience/foreducators/best/index.html), STEM Works (http://stem-works.com), Science Buddies (https://www.sciencebuddies.org), Engineering Go for it (http://teachers.egfi-k12.org), and Microsoft Education (https://www.microsoft.com/en-us/education/education-workshop).

Benefits of STEM Education

There are many benefits associated with STEM education. The author believes that those who learn STEM in an integrated approach are provided with an opportunity to see the "big picture" (i.e., how STEM is connected to the concepts or practices being learned). For example, in a STEM learning activity about wind power, students may be asked to build a wind turbine. In this activity, students will learn about renewable energy (science), and the consequences related to building wind turbines in a community (impacts of technology). Given a design challenge (engineering) with identified criteria and constraints, students will be asked to design and build a wind turbine (technology). Students will work in groups to build a prototype that creates blades to maximize the efficiency of their turbines. The wind turbine could be developed to either generate electricity via a motor (i.e., converting kinetic energy to electrical energy) or lift a weight via a drive shaft. Both models can be used to calculate the number of watts generated by the students' blades and the speed at which the turbine generates mechanical energy (science). Students can test their designs (collect and interpret data) by adjusting the size (area – math) of the blades, the shape, angle, and length of the arm (radius - math), to analyze which designs work most efficiently (Northeastern University Center for STEM Education, n.d.).

Others further identify the benefits associated with STEM Education. For example, The National Inventors Hall of Fame (n.d.) discusses the idea that STEM-based education teaches children more than science and mathematics concepts; it helps them develop real-world learning applications and needed 21st Century skills (e.g., technological literacy, problem-solving, critical thinking, collaboration, decision making, and leadership). Furthermore, Lynch (2019, paras. 2-9) notes the following benefits of STEM Education:

- It fosters ingenuity and creativity. Without ingenuity and creativity, the recent developments in artificial intelligence or digital learning would not be possible. These technologies were created by people who learned that if the human mind can conceive it, the human mind can achieve it.
- It builds resilience. Students learn in a safe environment that allows them to fail and try again.
- It encourages experimentation. Without a little risk-taking and experimentation, many of the technological advancements that have occurred in the last couple of decades would not have been possible. STEM encourages students to "try it and see what happens."
- It encourages teamwork. STEM education encourages students to work together (collaborate) in teams to find solutions to problems, record data, write reports, give presentations, etc.
- It encourages knowledge application. In STEM education, students are taught skills (e.g., problem-solving) that they can use in the real world and this motivates them to learn.
- It encourages the use of technology. STEM learning teaches kids about the power of technology (e.g., computers, 3-D printers, data collection devices, etc.) and to embrace them instead of being hesitant or fearful.
- It teaches problem-solving. STEM education teaches students how to solve problems by using their critical thinking skills (e.g., by brainstorming many solutions to a given problem).
- It encourages adaptation. STEM education teaches students to adapt the concepts and practices they learn to new problems, issues, or challenges that they face.

Another important benefit of STEM education is that it can introduce students to career opportunities in STEM. STEM jobs help keep a nation competitive and create new goods and services through research and development that can improve the overall quality of life.

The Need for STEM Education

STEM is Needed for Global Competitiveness

The need for STEM education arose from many countries' realizations that to stay competitive in the global economy, a STEM-educated workforce would be needed. For example, in the U.S., STEM has been recognized as a national agenda item: In 2018, the National Science and Technology Council's (NSTC) Committee on STEM Education (CoSTEM) released *Charting a Course for Success: America's Strategy for STEM Education,* which is a five-year strategic plan for STEM education (National Science and Technology Council, 2018). The strategic plan presents a vision for a future where all Americans will have lifelong access to high-quality STEM education and the U.S. will be the global leader in STEM literacy, innovation, and employment. The three major goals associated with the plan include the following:

- **Build Strong Foundations for STEM Literacy** by ensuring that every American has the opportunity to master basic STEM concepts and to become digitally literate.
- **Increase Diversity, Equity, and Inclusion in STEM** and provide all Americans with lifelong access to high-quality STEM education, especially those historically underserved and underrepresented in STEM fields and employment.
- **Prepare the STEM Workforce for the Future**—both college-educated STEM practitioners and those working in skilled trades that do not require a four-year degree—by creating authentic learning experiences that encourage and prepare learners to pursue STEM careers (p. v).

The goals listed above are important for all nations to consider as they develop and deliver STEM education. In addition, the report notes the importance of developing partnerships between schools and local businesses to bolster work-based learning and encouraged helping students learn STEM concepts through project-based learning, solving real-world problems, and boosting digital literacy. The term "digital literacy" has many interpretations. Heitin (2016) notes that the *American Library Association's* digital-literacy task force defines it as "the ability to use information and communication technologies (ICT) to find, evaluate, create, and communicate information, requiring both cognitive and technical skills" (para. 4).

In Europe, the *European Schoolnet* has recognized the importance of STEM Education. The European Schoolnet is a network of 34 European Ministries of Education and has noted that "skills in STEM are becoming an increasingly important part of basic literacy in today's knowledge economy" (European Schoolnet, n.d.). They have been involved in more than 30 STEM education initiatives, including *The STEM Alliance* (http://www.stemalliance.eu) that brings together industries, ministries of education, and education stakeholders to promote STEM and STEM careers to young Europeans and address anticipated future skills gaps within the European Union and *Scientix* (http://www.scientix.eu) that promotes and supports a Europe-wide collaboration among STEM teachers, education researchers, policymakers, and other STEM education professionals.

In ASEAN, (i.e., the *Association of Southeast Asian Nations*) it appears the teaching of and need for STEM education are still emerging. For example, Chen (2017) notes that ASEAN promotes multilateral cooperation, economic growth, and social progress, and to be a key player in the marketplace must promote developing a STEM workforce. In 2019, the World Economic Forum released the report entitled *ASEAN Youth Technology, Skills, and the Future of Work*. Based on a survey of 56,000 youths aged 15-35 years old from six countries the report noted that "ASEAN youths believe they are more competent in soft skills than in hard skills," and ASEAN youth regard their weakest skills as those in the STEM areas (e.g., technology design, data analytics, and math and science (p. 14). However, the report noted the strong desire from ASEAN youths to work in the technology sector. If their desire is to work in the technology sector, ASEAN countries must continue to recognize the importance of STEM education and prepare its youth in the STEM subjects.

SEAMEO is a collaboration of the 11 Southeast Asian education ministers, who have acknowledged the importance of STEM and in 2019 established the SEAMEO Regional Centre for STEM Education (SEAMEO STEM-ED) in Bangkok, Thailand. This center can help prepare youth in many ASEAN countries as the goals of the center are to develop, maintain, and continuously strengthen capacities in STEM education, serving as a regional knowledge repository and creator through high-quality research in STEM education both in Thailand and within the SEAMEO region (SEAMEO STEM-ED, n.d.b)

The importance of STEM education seems to be recognized around the globe. In addition to the U.S., Asia, and Europe, STEM is recognized as being very important in most countries today. For example, the Australian Government regards high-quality STEM education as critically important for their current and future productivity, as well as for informed personal decision making and effective community, national, and global citizenship and have developed a strong set of *School STEM Initiatives* to increase engagement in STEM (Australian Government, n.d.).

In Africa, where nearly 17% of the world's population lives (Worldmedia, n.d.) STEM education is still evolving as the region is challenged by such things as poverty, poor health, lack of infrastructure, and food insecurity, which are traceable to Africa's low investment in science, technology, and innovation (ADEA, n.d.). UNESCO's 2017/18 Global Education Monitoring Report entitled *Accountability in Education: Meeting our Commitments* notes that "only 22% of primary schools in sub-Saharan Africa have access to electricity" (p. 226) and very few have internet access (p. 380) (UNESCO 2017/2018). In its discussion on STEM education in Africa, STEMpedia (2019) recognizes the importance of STEM education and notes that Africa "has the potential to contain some of the world's fastest-growing economies, but it can only compete with the rest of the world if it invests in STEM education for young people (p. 1). This is supported by the Association for the Development of Education in Africa (ADEA) and their Inter-Country Quality Node on Mathematics and Science Education (ICQN-MSE) unit who has developed strategic objectives that promote STEM Education. These objectives are 1) Promote African-led mathematics and science education platform to advance the adoption of policies and practices including ICT integration in education, 2) Foster regional cooperation in the utilization of interventions and practices to strengthen individual, institutional, and societal capacities to advance STEM education, and 3) Leverage diverse sustainable partner networks for STEM education to promote exchange and knowledge sharing among educators in Africa (ADEA, n.d., para. 10) and if realized, they can help advance STEM education in Africa.

Technology is more than computers and the Internet. Technology is about modifying the natural world to meet human needs and wants. A popular technology today is the smartphone, but technology (e.g., an ax or spear) has existed since the beginning of humankind. Technology is part of STEM and it changes rapidly. With these changes come new STEM careers that may appeal to students and help to keep a country globally competitive. To learn about these new jobs, teachers should keep informed about new technology and their related careers. For example, Duggal (2020, paras. 4-27) provides a discussion of eight new technology trends for 2020 that students may find appealing in which to pursue a career. These trends include:

- Artificial Intelligence (AI);
- Machine Learning;
- Robotic Process Automation or RPA;
- Edge Computing;
- Virtual Reality and Augmented Reality;
- Cybersecurity;
- Blockchain;
- Internet of Things (IoT).

STEM is involved in Almost Everything

STEM is ubiquitous and impacts almost all aspects of our lives. Students who learn about STEM and how it is integrated become informed consumers who can make knowledgeable decisions about the goods and services they use or may someday come to rely on. For example, STEM is involved and necessary in the development of new electronic products and systems (e.g., smartphones, wireless networks, computers, and artificial intelligence). STEM makes possible safe and efficient transportation systems that move people and goods locally and globally, communication systems to keep us informed, and all aspects of healthcare require workers who possess good knowledge and skills in STEM.

The basics people need to survive are food and shelter. The production of both require knowledge and skills in STEM, especially to ensure our safety. Agriculture (i.e., “the art and science of cultivating the soil, growing crops, and raising livestock,” [National Geographic, n.d.]) provides us with food and is reliant on STEM to make sure our food is safe and abundant for all. Today’s agriculture production provides us with foods, fuels, fibers, and raw materials (Chait, 2020), and STEM is typically needed in all aspects of production. For example, students who learn about STEM and its role in agriculture may be able to better understand the making of “plant-based meat substitutes,” the problems associated with pesticides and fertilizers, or how farming in water (i.e., hydroponics and aquaculture) can be used in food production.

The building of shelters relies heavily on workers who have good STEM knowledge and skills. The building of houses, apartments, condominiums, or hotels requires STEM professionals to develop and build safe structures and install systems (e.g., electrical, water, waste, communication, and heating and cooling) to meet daily living needs.

STEM is involved in almost everything. From cooking and cleaning, to making movies, or building cell towers, STEM has touched some aspect of it. Today's education at all levels should introduce students to the role of STEM in their lives and introduce them to STEM-related careers.

STEM is Needed to Solve Global Problems

In 2018 the world witnessed a Thai boys' soccer team trapped in a cave in Northern Thailand that became flooded. That incident became a world-wide story as STEM professionals from around the world came together to solve the problems of getting the 13 trapped team members out of the flooded cave. It took the knowledge and practices of science, technology, engineering, and mathematics to safely get all the members of the team and their coach out of the cave and it was successfully achieved. In the rescue of the trapped team, lots of STEM knowledge and practices were used. For example, technology and engineering were needed to pump water out of the cave, bring fresh oxygen to the team, and set up ways to communicate with the team. Science was used to study the geology of the cave, for example using technology such as drones, zoom lenses, and thermal cameras to create 3-D aerial maps (Mirchandani, n.d.).

Knowledge of science was also needed to develop the compressed air for the rescuers to breathe and was needed in the development of the sedatives used to relax the trapped team members for their journey out of the cave. Mathematics was used to measure water flow rates, time, and distance. As Uppuluri (2018) notes, "the power of science and technology made it possible for this team to be brought to safety" (para. 6).

There are many global problems the world faces that will require STEM professionals to solve. The most pressing at the time of this writing is the global coronavirus disease (COVID-19) pandemic where STEM professionals from around the world are working to find a vaccine. However, this is not the only global problem the world faces. For example, in 2008 the National Academy of Engineering (NAE, n.d.) identified *14 Grand Challenges for Engineering in the 21st Century.* These challenges (e.g., make solar energy economical, provide energy from fusion, provide access to clean water, or engineer the tools of scientific discovery) are still relevant today and most will require STEM professionals from around the world to find solutions to the problems.

The Bill and Melinda Gates Foundation (n.d.) has identified a set of global grand challenges to solve global health and development problems (e.g., increasing demand for vaccination services) and most of these problems will need to be solved by STEM professionals working together to develop innovative solutions to the problem. Also, the United Nations (n.d.) has listed a set of global issues (e.g., food and water) and a set of 17 global goals (https://www.globalgoals.org) that the world needs to address and most of these will require knowledge and skills in STEM. Hutt (2016) from the World Economic Forum lists 10 key global challenges (e.g., food security and healthcare) that will require cooperation from STEM professionals to solve. Nebehay (2020) discusses how the United Nations notes that natural disasters (e.g., drought, floods, earthquakes, tsunamis, wildfires, and extreme temperature events) have surged in the past 20 years and that they are likely to continue to wreak havoc in the world. World disasters will continue to challenge STEM professionals to develop proper warning systems and ways to quickly deliver help to those affected by the disaster.

Those who teach some aspects of STEM should introduce STEM-related global problems into the curriculum for students to solve. For example, Gentile and Hoke (2011) looked at global problems as a framework for integrated STEM learning in the first year of college and note that "the major scientific challenges of the twenty-first century will require interdisciplinary teams to collaborate using tools from a variety of disciplines" (para. 1). To address this situation, they developed a first-year course called Integrated Quantitative Science (IQS) that incorporated first-semester content in biology, chemistry, physics, mathematics, and computer science. Although there were some challenges, they viewed the course as successful as the course deliberately integrated the STEM disciplines in the context of global issues, both in the classroom and in the undergraduate research experience.

Conclusion

Today, STEM is involved in almost all aspects of daily life. Beginning at an early age, students need to learn about STEM and how it impacts their lives. Learning about STEM may help students better understand the topic being presented and get them interested in pursuing a career in a STEM-related field.

Teachers who include some aspects of STEM in their lessons must accept the challenge of making STEM integrated into their teaching and learning experiences. STEM integration is a method of teaching that purposely tries to show how the areas of STEM are connected and it promotes the use scientific inquiry and engineering design by instructors in the development and delivery of lessons that often challenge students to find solutions to real-world problems.

Most primary – grade 12 teachers, whether they realize it or not, are very likely teaching some aspects of STEM in their curriculum and lessons. The author challenges them to learn more about the concepts and practices of STEM and integrate them into the materials being presented. For example, having students complete a hands-on real-world engineering design challenge is not only motivating and fun, but it can help improve student learning. It can also help students develop the problem-solving and other 21st Century skills they need to compete and survive in the global economy while integrating science, mathematics, and technology.

The author believes that the need for STEM education is now more important than ever and has offered reasons why all students (i.e., Primary - Grade 12) today need to learn about STEM in their studies. The reasons presented include that STEM education is needed for global competitiveness, that it is involved in almost everything, and that STEM professionals working together will be needed to solve global problems. Also important is how STEM education promotes student learning of key analytical skills that will be needed to compete in today's (and tomorrow's) global economy.

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Demonstration of STEM Education for Underprivileged Students: Impacts from Environment and Motivation

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Abstract

This study demonstrates the positive impacts of STEM education on the learning and development of the underprivileged students at Kaenthong Upathum School, Bangkok Metropolitan Administration under the Ministry of the Interior. The aim was to strengthen science skills while integrating an environmental problem and students' motivation into the development of an experiment. Poor air quality, which has negatively affected the school and its surrounding communities, is mainly caused by burning dry leaves from a nearby public park. The solution was to experiment the use of "pot rests" (a woven basket of bamboo) to store dry leaves for a production of fertilizer. Assessment and evaluation are based on this product (instead of preparing a report on an experiment). This shift is needed since most of the underprivileged students need extra income (from a sale of fertilizer) and plan to work after their graduation. Thus, examination and grade have not motivated the students. Finally, team teaching, outdoor experiment, engaging with foreign business associations (namely Joint Foreign Chambers of Commerce in Thailand) have played an important role in this study. A brief example on mathematics is also shown. Key learning points, based on the students' comments, are discussed.

Key words: STEM, environment, motivation, feedback, underprivileged students

Integrating the subjects of science, technology, engineering and mathematics (STEM) into a development of lessons and experiments for underprivileged students has been a challenge. In Thailand, this challenge stems from many reasons, including qualification of science teachers, suitability and school context, and budget to sustain and support science experiments (Fry and Bi, 2013). Unfortunately, the design of science education is based on the presumption that the students continue to further their education after high school (Faikhamta and Clarke, 2015, and O'Riordan, 2018). Thus, all students are required to learn similar subjects for the university admission's test. As a result, vigorous science experiments and examinations play a key role in motivating the students to learn and understand science (Hallingerand & Bryant, 2013).

Interestingly, Thailand has two public agencies primarily responsible for education, i.e., the Ministry of Education and the Ministry of the Interior. For the Ministry of Education, there is the Office of the Basic Education Commission (OBEC), which oversees the 12-year compulsory education and is responsible for administering more than 30,000 schools throughout the country. On the other hand, local municipalities under the Ministry of the Interior are responsible for health and human services to local populations, which includes education (Sanpnapaboworn, 2005).

How is the Ministry of the Interior involved in Thailand's education? In the past, a daycare was part of social services and as a result, it was handled by the Ministry of the Interior. Due to the isolated location and low population density of these daycare centers (where it was not feasible to build a school to be administered by the Ministry of Education) and the poverty of the local population, a daycare center was extended to provide primary education from Grades 1 to 3. This extension was granted until some of these schools were able to provide teaching at the upper secondary level (from Grade 10 to 12). The Ministry of the Interior oversees both autonomous areas, which are Bangkok Metropolitan Administration (BMA) and Pattaya City Administration (PCA) as well. Approximately, 12% of the entire student population (about 800,000 students) are currently attending the schools supervised by the Ministry of the Interior. BMA alone is presently handling 437 schools and 350,000 students.

Despite the numerous efforts to improve the quality of teaching and learning at these schools under the Ministry of the Interior, the achievement based on the national assessment shows that a gap exists when comparing scores with those from the Ministry of Education as well as from the higher educational institutes with Faculties of Education (OECD/UNESCO, 2016). There are several reasons that have contributed to this gap (Fry, 2002; Faikhamta, 2011; and Faikhamta and Clarke, 2015). Student motivation and frequent school transfers for a student (due to the migration of the parents who need to seek work constantly), poverty, a school's readiness (due to various functions of the Ministry of the Interior, which is also responsible for security, drug suppression, and law and order), and quality of teacher (due to frequent requests to transfer to the Ministry of Education), and lack of a systematic teacher training mechanism) have been cited as the key contributors to this gap. See Table 1.

Table 1

The 2011 Scores from Trends in International Mathematics and Science Study (TIMSS)

School Category	Science	Mathematics
University Teacher Training (Demonstration or Laboratory) School	552	554
Ministry of Education (only Public School)	472	460
BMA Schools (part of Ministry of Interior)	447	425
Ministry of Interior Schools	440	424

Source: Department of Education, BMA

Problem Statement

As previously mentioned, STEM education for underprivileged students can be difficult primarily due to a school's readiness and a lack of affordability of students to attend a university. Regarding readiness, the gap comes from a science experiment, which is designed for students who plan to take a national admission test. Thus, a school where most students cannot afford to continue their education after their high school completion is placed at a disadvantage.

This contributes to the perception that science education is only for those who plan to study medical, basic, and engineering science at a university. Science for few, instead of science for all, has been in the mindsets of students and teachers alike at the schools under the Ministry of the Interior. When the term "STEM" becomes part of pedagogical practices of science and related experiments, more confusion emerges. This confusion is based on the perceived inability to explicitly include and blend all four terms into a development of a lesson and an experiment. Some interpret that STEM topics, especially for a science experiment, must encompass Physics, Chemistry, Biology, Technology, Engineering, and Mathematics.

Such a complex experiment cannot be expected comprehensively at a school under the Ministry of the Interior. In addition, a difficult experiment may not be helpful due to a lack of opportunity to further extend the subjects and content at home. It should be noted that, also, the students cannot afford to attend special tutoring sessions and lessons to discuss these advanced areas. The motivation to learn for the underprivileged students became the major concern, given the gap in their fundamental knowledge, which is likely to lag behind their more well-off peers. A lack of compatibility of science experiments in the local context has further deepened this problem.

Motivation to learn science education by underprivileged students has been an important issue. Because these students cannot afford to continue their education in a university, a lack of interest to learn and understand the intensive science contents and subjects is obvious. Despite this, the need for them to have science skills could not be ignored and was viewed as a priority. It is generally recognized that science skills are the foundation for soft skills, life skills, and employability (Deep et al., 2019). Hence, most underprivileged students seek employment after their graduation from high school. Specifically, for BMA schools, the schools are in the densely populated urban areas with limited space on campus and budget to have a comprehensive STEM laboratory. See Figure 1.

Objective

The study attempted to apply a local-context circumstance to improve science skills. The primary objective of the study was to gain more insights into how STEM education can be effectively applied for the underprivileged students. The study took place at one BMA school (Kaenthong Upathum School). A science experiment (which combines science, mathematics, and environment as well as the empathy of students' need) was planned and implemented.

Note that integrating environmental issues into a lesson-plan development for science education was encouraged (see Appendix A). In this study's circumstances, the environmental problem directly impacts the quality of life of students and residents in the surrounding communities alike.

Figure 1

Example of a BMA School and Classrooms

Method

In this ongoing study, which began in 2016, several steps have been taken for the development of a science experiment. These steps have incorporated the ideas from students and have adapted many conceptual frameworks and practices (e.g., team teaching and feedback and motivation). An engagement with an external entity (especially with Joint Foreign Chambers of Commerce in Thailand or JFCCT) was made in 2016. This engagement was needed to help blend external feedback to motivate students' learning and development. Note that the tasks and similar experiments have been carried out and repeated at the beginning of a semester for the past four years (from 2016-2020). In reference to the beginning of the study, four specific steps can be described as follows.

The first step was to explore surrounding environments and problems nearby the school. Again, the study took place at Kaenthong Upatham School, Prawet District. The school is on the outskirts of Bangkok.

The next step was to examine the circumstance that could lead to a lesson plan development. Due to the lack of a proper laboratory to conduct an advanced science experiment, performing an outdoor experiment was viewed as a viable alternative for the students.

Third, a team teaching session was organized for planning, which aimed to include crucial science knowledge, including mathematics. Afterwards, engaging with the students in mapping and surveying a focused area was conducted. In this step, skill development was emphasized since science skills were to be an integral part of a science experiment (instead of merely focusing on completing an experiment and writing a report relating to science subjects and contents). The focus on science skills included teambuilding, observation, note-taking and record keeping, discussion, etc. These skills were also viewed as critical for the future employability of the underprivileged students.

The next step was to consider the student's motivation in the design of an experiment. Therefore, reaching out to the private sector was necessary. JFCCT, through its Education and Skills (E&S) Committee, was reached and they later agreed to work with Kaenthong Upatham School. Note that the E&S Committee had been working with BMA since 2015 when its chairman was appointed to be an advisor to the BMA Governor. Later, the feedback from the students from three different years was gathered to learn about the impacts from the revised pedagogical practices.

Findings

Team teaching was one of the major changes in the preparation of a lesson plan for a science experiment. In the past, all four major science subjects (i.e., Physics, Chemistry, Biology, and Mathematics) were prepared and taught separately. Due to the serious problems with water and air pollution, the teachers decided to focus on environmental and ecological issues by using the International Environmental Education Programme initiated by UNESCO and UNEP (Hungerford & Peyton, 1994) as a guideline. This framework stresses the need to collaborate and integrate various science contents and subjects since many complex problems could not be tackled independently.

The group of science teachers used the above framework to organize the subsequent tasks and activities for the students such as survey and problem understanding, impacts, learning and analysis, implementation, and knowledge exchange and sharing. It was important that the teachers initially investigated and evaluated the suitability of an area to be used for an experiment before allowing the students to survey and learn about the location. For the survey task, the use of mobile phones was encouraged among the students due to available open software (which is free of charge).

For Kaenthong Upatham School, the teachers agreed to tackle the problem of air pollution caused by burning dry leaves near the Nong Bon Lake (part of Bangkok's "monkey cheeks" [a Thai term for constructing small terraces and ponds] for flood control). This area is designated as a public park with lots of trees and picnic areas. To handle large piles of dry leaves and trashes from the visitors, the district administration sorted this problem through daily burnings. As a result, air pollution became a serious problem for the school and its surrounding community. See Figure 2 for team teaching and student tasks on a survey and documentation of the findings. See Appendix B for more details.

Figure 2

Location Survey through Team Teaching and Student Teamwork

For the next step, a fertilizer was chosen as a product which would reflect the understanding of science subjects and content. A production of fertilizer would be based on dry leaves, trash, and food waste (from a school as both breakfast and lunch are provided to the students). It was critical to extend an experiment into product development. The reason was that JFCCT Education and Skills Committee was exploring an opportunity for foreign business communities to be involved and to participate in skill development of the students, especially employability.

Consequently, the teachers decided to use the traditional concept of a "pot rest" (or in Thai, called Sa-Wean [เสวียน]), which is a woven bamboo basket, for fertilizer production. A pot rest generally uses dried bamboo, which is wrapped around the base of a tree to help store various components for fertilizer. In other words, the pot rest would be used for collecting leaf and other wastes, which would reduce the need to burn the leaves and lead to the production of fertilizer. The students would then try to promote and sell their fertilizer to local communities and the general population for extra income. See Figure 3.

Figure 3

Pot Rests (Sa-Wean) Used for the Science Experiment

From this decision, many detailed lessons and activities could be subsequently developed. To make a pot rest, the students needed to first cut the dry bamboo into approximately one meter lengths, which were used as stakes to be driven into the ground. The students then needed to hammer the stakes into the ground while leaving the remaining part about 100 cm above the soil. The distance between the stakes was suggested to be 20 cm. Approximately 13-15 stakes are needed for a large tree. Finally, the students were required to chop the bamboo into smaller long lines and to tie these pieces around the stakes. See Figure 4.

Figure 4

Pot Rest Construction and Experimentation

To further demonstrate the results from this step, a mathematics lesson is shown below. The lesson and exercise were part of the preparation of the students to produce fertilizer. During a lesson, the students were asked to estimate the volume of the combination of dry leaves, trash, and food wastes to be collected. This lesson was taught while the students began to experiment with a pot rest. For a determination of a pot rest's height, the students were challenged with the following question. If there was a need to have 3.5 cubic meters of dry leaves, trash, and food wastes in each pot rest, how high would a pot rest need to be for a radius of one meter? The formula is as follows:

Volume $= \pi(r^2)(\text{h})$, where

- "r" is denoted for radius in meters
- "h" is denoted for height in meters

Thus, for the required volume of 3.5 cubic meters, the height of a pot rest would be around 1.11 meters. This was based on: $3.5 = 3.14(1)^2(\text{h})$.

It is important to point out that different scenarios and soil sensitivity studies were conducted to analyze the impacts from the amount of water used and the temperature. Ensuring the students' awareness of various parameters for fertilizer was critical. See Figure 5 for the experiment that led to the production of fertilizer and its extension in later years. An extension from fertilizer production was made to grow contamination-free vegetables for nearby shops and hotels, which generated a considerable income to the students. Through JFCCT's partnership with "Spouses of Head of Mission," the Embassy of Luxembourg donated a facility to the school for this purpose.

Figure 5

Science Experiment and Product Development for Underprivileged Students

A series of workshops (sponsored and organized by JFCCT) on improving the students' products (including fertilizer) was conducted in an active participatory manner with students and teachers. The focus of these workshops was on basic business and entrepreneurship skills, which included packaging, labelling, and storytelling. Involving foreign business communities was constructive and creative due to the sense of belonging and the high level of excitement for the students. Commercialization of students' products from the science experiment was necessary since the students need extra income to support their daily living. See Figure 6.

Figure 6

Demonstration of Product Improvement from JFCCT's Workshops

In general, the responses and comments from the students have been largely positive. They felt that they could relate the experiment with their context and situation. They could connect to this experiment because it would help lessen the impacts from air pollution on their school and surrounding communities (i.e., their parents and family members). A sense of problem ownership was significant to them. An opportunity to conduct an experiment was also crucial. The students appreciated an opportunity to take part in a hands-on experiment. Use of their mobile phones was not an issue for the underprivileged students. The follow-up meeting also revealed that they clearly welcomed an opportunity to learn and engage with foreign businesspeople. The responses highlight the significant impacts of a combination of hands-on experimentation and commercial development of a product (from an experiment). See Appendix C for the summary of the students' comments.

Discussion and Implications

The study illustrates the positive impacts of STEM education on learning and skill development of the underprivileged students. Despite the lack of readiness for conducting more advanced science experiments, this difficulty should not hinder an opportunity to gain science knowledge and more importantly science skills for these students. Although not all underprivileged students are able to pursue a university-level education, science education should train and prepare them for their future careers and employment. Essentially, STEM education should not only provide the students the needed knowledge (i.e., science subjects and content for higher education), but also prepare them (for those who cannot afford to continue their education) the skills for employability.

During the experiments, the students experienced a lot of opportunities to interact among themselves, which improves their communication and teamwork skills. Presentations of their findings to their peers and to foreign business communities helped motivate learning and personal development. The positive impacts on the students can be attributed to many factors.

The use of team teaching needs to be recognized. A lesson plan, which is integrative depends on the willingness among the teachers to work together (Chanmugam & Gerlach, 2013). To make fertilizer as part of a science experiment requires extensive planning and good teamwork from the teachers specialized in STEM subjects. It is important to point out that it is easier to encourage teamwork and communication to the students when they can observe it from their teachers. This is one of many unexpected comments made by the students (Hartnett et al., 2013).

The empathy of the teachers on assessment and evaluation is critical (Guerriero, 2017). Instead of conducting an experiment, which would result in a report on their discovery, it is also possible to assess and evaluate the understanding on the subject matters on product development. To be able to develop a product (i.e., producing fertilizer), the students need to apply and demonstrate science knowledge. This paradigm shift is important since many underprivileged students do not possess excellent writing proficiency. A lack of writing proficiency often restrains the students from expressing their understanding of the subject matter.

It is also important to recognize the importance of integrating an environmental problem and a local context into a science lesson. For the underprivileged students, a meaningful change from a traditional lesson is that they can work on what they perceive to be tangible and helpful to their livelihood. Ensuring that the students can relate science study to their context is critical for maintaining their interests and attention (Chan and Yung, 2015). For this study, outdoor experiments are more effective for science learning for the underprivileged students.

JFCCT has played a complementary role to the entire study. It recognizes that the active engagement with teachers and students and the responses to their needs through consultation and participation are essential. Design of the workshops needs to be based on the students' needs (i.e., something that they cannot learn from classrooms). Commercializing their experimental output as part of financial motivation is important for the group of the underprivileged students. This factor highlights the importance of feedback from an external source for learning and development of the students.

Motivation affects learning and development. In this case study, financial motivation was proven to be the necessity and needs to be considered for the underprivileged students when designing a science experiment. As previously mentioned, a product development should be allowed as part of a science experiment. Instead of a report (on proving the correctness of theories and concepts), which is subject to a numerical score or a grade, judging and evaluating students' learning can be more accommodating. This flexible mindset is crucial for the future development and implementation of STEM education, especially for the underprivileged students who mainly reside in densely populated or isolated rural areas.

It has been a challenge to motivate students' learning and development through an extensive report, a vigorous exam, and a numerical score when a student does not plan to continue his/her study. By blending constructive feedback from foreign business communities (e.g., feedback on product and possible improvements) and becoming more amendable to assessment and evaluation, the students have apparently reacted more positively. Less tardiness or absence reflect this positive reaction and attitude of the students.

In fact, this study underlines the significance of the feedback concept in teaching and learning. Feedback is fundamental for science education (Soraya & Moustaghfir, 2019). In addition, the feedback represents a mechanism for ensuring that a student completes a required task correctly during an experiment. From the observation, the underprivileged students appear to seek and appreciate constructive feedback, which can benefit their future careers, especially from someone outside a school. Furthermore, the feedback helps students improve their life skills on the need to seek input, the ability to listen and analyze, and the capability for self-improvement.

Finally, adapting science education to help the underprivileged students prepare their future careers represents an important step for future STEM development in a certain segment of the student population. Instead of focusing on the students who will continue their education at a university, science education can provide needed skills for future careers.

Conclusion

This study demonstrates the practices of STEM education for underprivileged students. In Thailand, despite the gap in education readiness (which is reflected on achievement scores), science knowledge and skills should not be restricted primarily to the students whose schools belong in the country's upper echelon. To make science education more attainable, a group of teachers from one BMA school, Kaenthong Upathum School, decided to apply environment as the foundation for the design and development of a science experiment. This was to ensure that an experiment is consistent with the students' life context. Motivation was also integrated into this study through financial incentive and constructive feedback from an external entity (namely JFCCT). The positive impacts from the students are illustrated and described.

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Appendix A: Guideline for Blending Environment into Science Education in Thailand

English translation from the original Thai (in box below):

“Topic 8: Nature, Science and Technology

Criterion 8.1: Using science-oriented processes to gain more knowledge and to develop problem- solving skill through the fundamental understanding of natural phenomenon. Need to observe and identify the pattern of the cause-and-effect relationships through an experiment based on the information and instruments. Need to recognize the interrelationships among science, technology, society, and environment.”

สาระที่ ๘ ธรรมชาติของวิทยาศาสตร์และเทคโนโลยี

มาตรฐาน ว ๘.๑ ใช้กระบวนการทางวิทยาศาสตร์และจิตวิทยาศาสตร์ในการสืบเสาะหาความรู้ การแก้ปัญหา รู้ว่าปรากฏการณ์ทางธรรมชาติที่เกิดขึ้นส่วนใหญ่มีรูปแบบที่แน่นอน สามารถอธิบายและตรวจสอบได้ภายใต้ข้อมูลและเครื่องมือที่มีอยู่ในช่วงเวลานั้นๆ เข้าใจว่าวิทยาศาสตร์ เทคโนโลยี สังคมและสิ่งแวดล้อม มีความเกี่ยวข้องสัมพันธ์กัน

Appendix B: Fact Finding and Lesson Plan Development for Pot Rest Experiment

1. Initial Surveys (from the teachers and the students): Ecology of the area to be studied
    - The marsh pond has decent soil condition, clay, loamy and sandy soil. The water system has a large pond in an area of 600 rai (or 237 acres) to be used for Bangkok's water storage. There are many different types of plants and small animals. And aquatic and local plants along the shore of the Nong Bon pond. Large amounts of dry leaves are visible during the dry season (about 7 months).

2. Use and benefits: local communities and students
    - Dense use of space is noticeable. It is a popular place to enjoy the city's nature, exercise, and practice a handful of water sports. The place is part of the storage during the rainy season for the city. It is also a place to study the ecosystem of living organisms.

3. Impacts and effects: local communities and students
    - Due to the inability to handle large piles of dry leaves, burning has been adapted extensively. This has resulted in the intense smoke by this incineration, which affects the air quality. The air pollution is a source of health concerns for people in the local communities and the students alike. In addition, water intake from different areas of Bangkok (both residential and industrial areas) has contributed to water pollution.

4. Situation analysis: air pollution
    - Situation: Removal of dry leaf and trash by incineration
    - Change: Intense burning has continuously resulted in an unacceptable level of air quality.
    - Phenomenon: Poor air quality affects outdoor activities of the students and the daily routine of people's livelihoods in the communities.

5. Experimental learning: focus of the study
    - Managing dry leaves and related trash to help reduce air pollution
    - Fertilizer can be an output of an experiment. Local communities and nearby residents are interested in using contamination-free fertilizer to grow fresh produce for their consumption.

Appendix C: **Summary of Student Comments**

The preliminary gathering of students' comments was made to provide the students an opportunity to express their sentiments about, and perceptions of, a new pedagogy. This data gathering exercise reflects the next phase which would involve a preparation for a more comprehensive survey study. It would deal with the student's perceptions of the usefulness and impacts on employability from science education. In general, students' initial opinions point to the strong possibility for effective STEM education despite the shortcomings of a laboratory's readiness.

Three simple questions were part of this data-gathering effort: challenges facing science education (for underprivileged students), preferred pedagogy to help strengthen science skills and knowledge, and use of daily digital devices such as mobile phones to support the science experiments for local-context problems (due to inadequate laboratory equipment and instruments). This is part of an attempt to improve quality of learning and development through more understanding of (or empathy for) the students.

The common responses from the students (about 40 students who are still studying and have recently graduated) can be summarized as follows:

- Students' comments point to the challenges that they had to overcome, which included a lack of opportunity to conduct hand-on experiments and feeling of being under pressure to work on irrelevant experiments to their contexts. Vigorous examination and complex experiments are not perceived as useful. It appears that the underprivileged students need an alternative to motivate their learning and development.

- An outdoor experiment which integrates environmental problem can improve soft skills (such as communication and teamwork) while injecting enjoyment and fun for the students. Finding a science problem that the students can relate to or identify with is a very important step for a successful science experiment.

- Instead of not being able to conduct any experiments, apparently the students are more receptive to using their personal devices for science-related activities. They appear to be more willing to use their mobile phones to help with their experiments as they recognized the shortcomings in a school's laboratory. This could imply that, despite their underprivileged background, the students viewed science as an important subject for skill development.

Building a Successful University: School Partnership for STEAM Education: Lessons from the Trenches

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Abstract

In this paper, we report on a successful U.S. university–school partnership to prepare science, technology, engineering, arts, and mathematics (STEAM) teachers and build STEAM leadership capacity based on the qualitative and quantitative data collected over two years. Our framework for a STEAM-integrated school and teachers was based on integrated learning theory supported by socio-constructivist, inquiry learning and context-based pedagogy. The university–school partnership for STEAM education supports the idea that the partnership to prepare STEAM teachers and school leaders should incorporate the issues and views of the stakeholders with a continuous feedback loop for better and effective professional development (PD). The university-school partnership for STEAM school teachers and leaders showed that despite initial challenges, success is achievable if the partnership is built of equal opportunities to learn and guide the outcomes. Our data analysis produced four key lessons of a successful partnership for an effective and sustainable STEAM teacher PD program.

Keywords: university-school partnership, STEAM education, STEAM teacher development, leadership, noncognitive skills

We argue that science, technology, engineering, and mathematics (STEM) disciplines provide significant and growing opportunities for students in building 21st century skills (Bryan et al., 2015). Furthermore, STEM education, if done well, builds critical pedagogical skills and practices in students. We assert that critical thinking, combined with critical pedagogy, would add value to STEM education because critical pedagogy would enhance students' ability to reflect and evaluate social and cultural issues supported by STEM knowledge. Students need to be well developed and educated in effectively and efficiently managing tasks that require complexity in thinking, ability to work in linguistically and culturally diverse communities, problem-solving, and systems thinking approaches (National Research Council, 2011). We also contend that STEM education means integrating curricular approaches through inter-and transdisciplinary interactions and grand challenges such as energy, environment, health, and food security. For our students to become well-rounded citizens of the globe, they also need to understand the values of language and arts within STEM education. Therefore, in this paper, we focus on science, technology, engineering, arts, and mathematics (STEAM) education. The addition of the arts disciplines allows for students to understand that art, which brings social, cultural, and political issues during STEM engagement, is an integral part of doing and engaging in STEM disciplines. In our conceptualization of STEAM, we firmly believe that the STEM disciplines are influenced by the social, cultural, and linguistic values and beliefs of a community and nation. Thus, STEAM presents greater possibilities for students and teachers to integrate grand challenges in the school curriculum and find connections between the STEM disciplines and the arts, which include language, social studies, and performing and other arts. Furthermore, if the goal of STEM education is to celebrate diversity of ideas and cultures, inclusion and equity are central parts of any university-school partnership that prepares teachers for teaching in a STEAM school (Eisenhart et al., 2015; Means et al., 2016).

Our goal in this paper is to report (a) the lessons learned in a university-school partnership and (b) the nature of university-school collaboration during the STEAM teacher PD program. We present our findings from a two-year teacher and leadership development partnership between the University of Minnesota and the Austin (Minnesota) Public Schools. The goal was to help prepare teachers for a fifth- and sixth-grade STEAM school (188 students) that the school district was preparing to open. Since conceptualization of STEM has been both varied and contested, we first present a brief review of current STEM conceptualization, followed by a university-school partnership for STEM/STEAM schools. Second, we present our model of the partnership for a STEAM school. Third, we present the methods of data collection and analysis. Fourth, we present four lessons of this partnership, and finally we discuss what this means to other university-school partnerships for STEM/STEAM.

Conceptualizing STEM/STEAM for Partnership

We have conceptualized STEM/STEAM through three lenses. The first is from the learning theory of integration (Frick, 2018; Martín-Páez et al., 2018; Pearson, 2017). Integrating multiple disciplines for better and more complete learning is rooted in the belief that everyday problems need knowledge and ideas from varied fields (Satchwell & Loepp, 2002; Thibaut et al., 2018). Therefore, our solutions are codependent on varied disciplinary and experiential knowledge (Upadhyay et al., 2017). Many supporters of integrated learning assert that student learning is better and more meaningful when students find varied disciplinary ideas and practices helpful in solving complex social challenges (Frick, 2018; Huber & Hutchings, 2004).

The second reason for integrated STEAM education relies on the value of inquiry learning. Inquiry learning supports students in developing both the kinds of questions they want to explore and how they want to explore them (National Research Council, 2000). Inquiry learning is best accomplished when students can integrate different disciplines and their sociocultural experiences, which allows students to make better sense of content as well as its connections to their sociocultural and local issues (Satchwell & Loepp, 2002). Therefore, integrated STEAM has potential to improve learning as well as engagement in STEM disciplines. The third argument for integrated STEM education is that learning takes place in a collaborative social and cultural environment, thus the sociocultural theory of learning, specifically social constructivism, asserts that learning is a collaborative, social process where ideas and discourses from different spaces and disciplines allow learners to generate new meanings or knowledge (Vygotsky, 1978). In this regard, STEAM disciplines provide remarkably conducive learning environments where students can draw from different disciplines and sociocultural experiences to engage in learning and doing STEAM activities (Brooks & Brooks, 1993). We specifically argue that without deeply rooted commitment in the sociocultural nature of learning, integrated STEAM education would not support student learning where local contexts and issues are essential. Therefore, place-based STEAM teaching and learning allows for culturally relevant learning among diverse students. Place-based STEAM teaching also provides better opportunities to engage in learning through local social, cultural, and socioscientific issues (Zeidler et al., 2013). Local social and cultural issues tend to tie to the STEM fields intricately, such as pollution (e.g., from coal-fired power plants), food-processing factories, urban infrastructures, health care, water management, flood management, and many others. Therefore, the third part of our conceptualization of STEM was based on how to bring these fields in direct contact with sociocultural, economic, health, and other socially important issues and make STEM more relevant to students and their communities. The social and personal nature of learning in a context provided us a compelling rationale to think about STEAM education rather than STEM education for our teachers and students.

Yet, studies in integrating different disciplines, specifically the efforts to integrate mathematics and science in the 1990s, showed mixed results (Czerniak et al., 1999). Some studies showed better learning (Beane, 1996; Berlin, 1994; Carnegie Council on Adolescent Development, Task Force on Education of Young Adolescents, 1989; McComas & Wang, 2010; Stevenson & Carr, 1993), and others showed challenges where integration was more forced and perfunctory rather than seamless and deep (Berlin & White, 1992; George, 1996; Lederman & Niess, 1997; Lehman, 1994). In the context of STEM/STEAM integration, until now, the results have been mixed as well (Eisenhart et al., 2015; Means et al., 2016). However, in our professional development (PD) of STEAM teachers, we focused on integrating different content areas more deliberately. So, in our PD we focused on integration from a socio-constructivist learning perspective, because it allowed us to incorporate STEM fields with English language arts areas more organically. We also recognized the value of socio-constructivist learning environments for support for inquiry-oriented, engaged, hands-on, and minds-on STEM/STEAM learning.

STEM/STEAM University-School Partnership

University–school partnerships are complex and challenging hybrid spaces (Zeichner, 2010). Many partnerships start with a considerable gap between the partners based on their goals and aspirations and expertise, knowledge, reach, and funding capabilities. Yet, we envisioned a partnership where we had possibilities to come together and marry our diverse thinking, ideas, resources, and experiences through collaborative negotiations and open dialogues (Darling-Hammond, 2006; Davies et al., 2007). We strongly believed in a university-school partnership that drew on trust, mutually agreed-upon goals (collaboration), and reciprocity (contribution of all) as three critical aspects of any successful and transformative partnership (Kruger et al., 2009). The partnership's eventual goal is to provide learning opportunities to all stakeholders, strengthen professional relationships, and help remove rigid boundaries for more mutually supportive structural spaces (e.g., Herbert et al., 2018). Partnership benefits need to expand beyond teachers, students, and schools. When the broader community is engaged, students and the community see broader connections between school learning and their community. STEAM education's central underlying premise is to make student learning more authentic to their environment. A successful university-school partnership requires a collaborative and mutually beneficial space where ideas and actions get challenged for better outcomes (Hargreaves & Fullan, 2012).

In our partnership, community leaders, parents, and experts were essential components because they brought complex local problems (Price & Vali, 2005) as entry points to engage students in STEAM thinking and learning and what they wanted to see in the STEAM school envisioned for their children. Similarly, our university–school partnership had open spaces for teachers to bring their voices from science, mathematics, social studies, language arts, computer technology, music, and sports. We also provided lunchtimes for community members to share their thoughts for their children and also for the STEM partnership. Research clearly has shown university–school partnerships thrive and have more buy-in in the potential change when teacher and community voices are heard and incorporated in the PD design and implementation (Berger & Johnston, 2015; Price & Vali, 2005). Additionally, we envisioned a collaborative partnership based on the outcomes on the meaning of STEAM teaching and learning, student improvement through STEAM integration, improvement in teaching practices and pedagogies, and STEAM teacher leadership. We further framed these outcomes around the school and student needs for a robust and sustainable STEAM school (Schulz & Hall, 2004; Sirotnik & Goodlad, 1988). Therefore, our partnership for STEAM teacher development was based on synergistic and equitable work that led to better decision-making, was meaningful and sustainable for the partnership duration, and eventually created a positive effect on learning (Essex, 2001).

Key Framework for a STEAM Partnership

As stated earlier, the major philosophical framework was based on the principles of improvement science (Berwick, 2008) and a short-cycle feedback loop (Park et al., 2014). Improvement science allowed us to focus on what works for addressing a particular problem (building STEAM teacher capacity and leadership), for whom, and in which contexts (Berwick, 2008; Bryk et al., 2010). Therefore, this framework allowed us to support and work with school teachers and leaders to locate challenges and provide context-specific local solutions in the existing structures, curriculum, and pedagogy (Bryk, 2009).

The short-cycle feedback process was essential to allow both sides to modify, adjust, and address concerns and change the direction of PD in a timely and ongoing fashion. Furthermore, the short-cycle feedback loop supported the workshop's design process and the adjustments in phases. Continuous feedback allowed us to be more open about STEAM teachers' needs and the early mitigation of potential problems when the STEAM teacher leaders had to lead their peers in new STEAM teaching and learning contexts. In this partnership, our feedback loop consisted of input from participants (mostly from teachers, principals, and the district coordinator and at times from the community), redesign of workshops by university experts, and feedback from the participants in the workshop, which guided us for the next workshop. See Appendix A for the design of PD and the feedback table.

Methods and Data Collection

The data in this paper come from a two-year university-school partnership. We employed a mixed-methods design (Creswell & Creswell, 2017) to document and understand lessons learned and the challenges of the partnership. We collected data through surveys, observations, field notes, interviews, and post-workshop reflection among the partners. The data collection was informed by our notion that voices from different stakeholders had to be valued and incorporated for a better and more open partnership that benefited everyone.

We analyzed data both qualitatively and quantitatively to help us learn the lessons of the STEAM partnership. Qualitative analysis was done holistically by looking for common themes in several types of data that we collected (Miles et al., 2014). We utilized quantitative data analysis to better explain qualitative themes to provide more robust evidence on the lessons that were learned. We generated four themes and called them "lessons learned."

Lessons Learned: University–School STEAM Partnership

In this paper, we present four lessons learned through a two-year PD partnership between the University of Minnesota and the Austin Independent School District in southern Minnesota. The four lessons are: (a) attending to the noncognitive features of STEM education, (b) letting teachers experience what the students experience in the classroom, (c) inquiry as access point for disciplinary teachers into the engineering process, and (d) building STEAM teacher leadership capacity. Before going into the details of the four lessons, we provide a short context of the partnership and the PD program.

University-School District Partnership

The goal of the partnership was to build human capacity of the STEAM teachers at a fifth- and sixth-grade school. The PD program over the two years focused on all STEAM disciplines as well as how transdisciplinary teaching and learning (Evans, 2015) could take place in the classrooms. The participants included the school principal, the STEAM school leadership team comprised of 12 teachers representing each of the disciplines at the school (science, mathematics, language, music, technology, and social studies), and 36 other teachers who would be teaching at the fifth- and sixth-grade STEAM school. The university team provided monthly PD for the leadership team with consultation and feedback after each of PD meeting. The leadership team had eight PD meetings with the university team. The leadership team members facilitated PD for the 36 teachers who would be working in the STEAM school. During all teacher PD days, the members of the leadership team acted as facilitators in small-group settings for discussions and activities, while the university team led the overall PD program. This set-up provided means and opportunities for the school leaders and the leadership team to build their leadership capacities as well as own the learning at all teacher PD days.

We had set up the PD where the focus was a theoretical background supported by hands-on exploratory interactions with colleagues, the university experts, and the school leader. We also drew various activities from an existing engineering curriculum, Engineering is Elementary (EiE) developed by the Boston Museum of Science. Since many teachers expressed fear and lack of knowledge about engineering and engineering practices, in consultation with the leadership team, we used modified activities from the engineering resource book to give teachers a firsthand experience of doing engineering activities with complete design cycles. This helped settle the nerves of many teachers by the third PD meeting. We believed that small-step changes would provide lasting and manageable bigger transformation in teachers' thinking about engineering and engineering practices. The teachers were more comfortable engaging with other parts of the STEAM disciplines. From our data based on the PD times and conversations with the participants during and after the PD, we found four important lessons that stakeholders at any STEAM school need to consider for a successful STEAM initiative and STEAM teaching and learning.

Lesson 1: Attending to the Noncognitive Features of STEAM Education

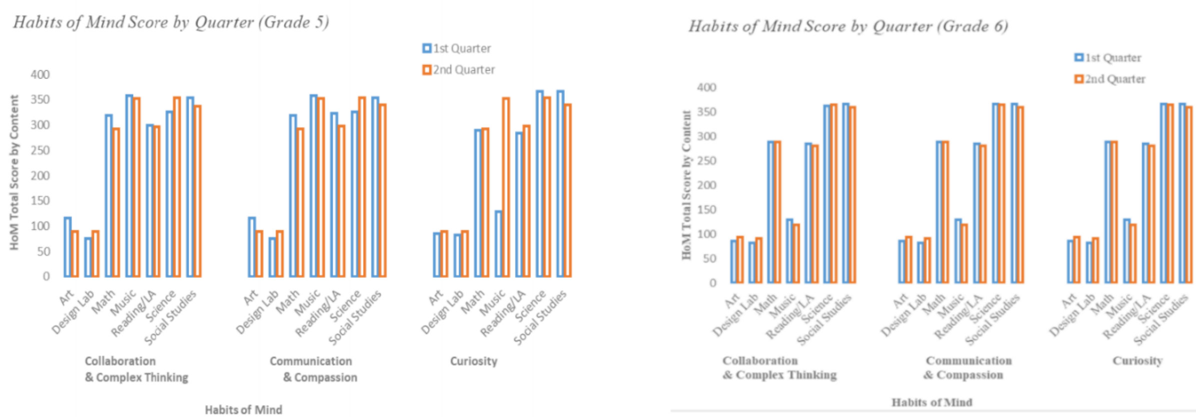
One of the big challenges in STEAM teaching and learning is the many variations and similarities between the nature of interactions, skills, ways of thinking, and nature of practices inherent in each of the STEAM disciplines. For students to successfully engage in and learn about STEAM fields, they need to understand and practice how to be a scientist, technologist, engineer, artist, writer, and mathematician at the same time and with purpose. The teachers involved in the PD wanted to measure skills and practices that were essential to having STEAM literacy. One of the teachers asked, "I understand that content is important, but how do we build good STEAM practices in our students? How do we make sure that our students do homework and do collaborative work?" We took this question and discussed the value of noncognitive skills in STEAM disciplines. Some teachers suggested grading students for timeliness, completion of assignments, self-responsibility, and personal accountability, the noncognitive skills required to be successful in STEAM fields. The teachers called these "life-skills." We wanted to get away from anything that could be perceived as punitive or imposing values that did not fit with many students who were from recent immigrant and nonwhite families. We strongly believed that in the case of the STEAM school, the cultural values and beliefs of many white teachers did not match with the cultural values and beliefs of many students from immigrant and nonwhite families, thus creating an unproductive learning environment for these students (Upadhyay, 2006; Upadhyay & DeFranco, 2008).

The STEAM teacher leadership team and the university team used the concept of habits-of-mind (American Association for the Advancement of Science, 1990; Costa & Kallick, 2009; Council of Writing Program Administrators, National Council of Teachers of English, & National Writing Project, 2011; Hetland et al., 2007; Katehi et al., 2009) borrowed from Costa and Kallick (2009) and the National Research Council's (2011) report on successful STEM schools ideas as a basis for a new life-skills rubric. The idea of habits-of-mind for the team was based on Costa and Kallick's notion that people have certain dispositions that they utilize in solving complex local and global problems that may or may not have readily available solutions. For the purposes of our partnership, these skills were (a) systems thinking, (b) creativity, (c) optimism, (d) collaboration, (e) communication, and (f) ethical considerations.

The PD team from the university and the school leadership team designed a habits-of-mind rubric to assess what noncognitive skills and practices students should learn as they attend the STEAM school. The school developed the habits-of-mind rubric (Appendix B) focused on three important components of STEAM disciplines: collaboration and complex thinking, communication and compassion, and curiosity. The team chose to name this set of habits-of-mind the "3Cs." The rubric was presented to all of the teachers, and their input became part of the rubric with multiple rounds of revisions. Through our discussions and interactions with the teachers during PD days, we discovered that these three broad habits-of-mind captured all the components of life-skills that the STEAM school teachers felt important. The focus was on the ownership of new ways of engaging with students and building a more inclusive school environment that would prepare students for content mastery as well as noncognitive skills called the habits-of-mind.

Figure 1 shows habits-of-mind scores in each of the 3Cs areas in various content areas given by fifth- and sixth-grade teachers for two quarters during this partnership. Appendix B shows the scale (1–4) and descriptors. The data show students' habits-of-mind growth between two quarters of STEAM schooling. The data clearly show students' habits-of-mind are robust in science and math but much desired in design labs. Thus, STEAM integration did not have the desired results in design labs, which are closely connected to engineering.

Figure 1
Habits-of-Mind Scores for Grades 5 and 6



Lesson 2: Having Teachers Experience What Students Experience in the Classroom

One of the biggest challenges for the university team was to build teachers' and school leaders' capacity as effective STEAM teachers at the new school. The university team also understood that the teachers were most fearful of how to teach engineering content and, as one teacher put it, "how to deal with effective practices of engineering." For a lasting change, our STEAM PD needed to provide engineering experiences that the teachers could use in their early STEAM classes and be comfortable with thinking about engineering and doing engineering. The school teacher leadership team chose the "Water, Water Everywhere" activity from the EiE curriculum because a river passes through the community and is a focal point of many school and community activities. Furthermore, a local meat-packing plant uses a lot of water from the underground aquifer, and treated waste water from the plant is mixed into the river.

The teachers were engaged in learning about the engineering design cycle and designing a system that would filter waste or polluted water. This was the first time the teachers experienced the steps of an engineering design cycle, while designing a filter system to remove pollutants from the waste water that could go into the local river. The teachers used soil, pebbles, tea, wheat flour, cornstarch, and food coloring as pollutants to test the filter. One of the most revealing observations was that the teachers became "more comfortable about engineering and how an engineering experience would work for a student." One teacher added,

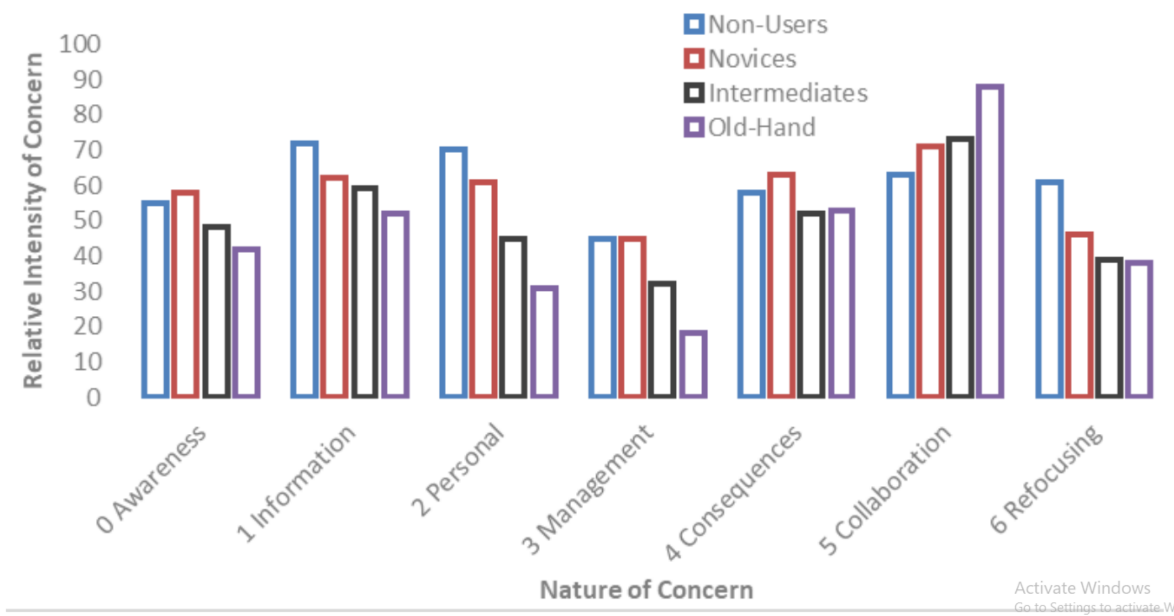
"If I had not done this activity with filters, I would have not felt comfortable even talking about engineering. Now STEAM makes sense to me because I can bring economics, social and cultural values, and ordinary everyday practices like washing vegetables in the river in my teaching. I am not a science teacher, but now I can talk about the filter [activity]."

Clearly, the experience made the teacher comfortable at something new and useful.

Furthermore, our survey of modified stages of concern (Hall, 1977) showed that teachers needed support to feel comfortable to give STEAM-focused instruction and engineering design practices in their teaching. This provided us with what we needed to cover in the PD for the teachers. The teachers were divided into four categories: nonusers (who believed they did not use STEM/STEAM in their teaching), novices (who used occasional STEM/STEAM in their teaching), intermediates (who used STEM/STEAM frequently in their teaching), and old hands (who had been using some kind of STEM/STEAM often in their teaching). Figure 2 illustrates the levels of concern and the need for more collaborative and directed PD for STEAM teaching and learning.

Figure 2

Self-Reported Levels of Concern



Note: N = 30. Results from the Stages of Concern Questionnaire of teacher concerns regarding expertise in science, technology, engineering, arts, and math (STEAM).

In another engineering activity about renewable energy, the teachers wanted to do a modified windmill activity based on an EiE unit. A local windmill farm was community supported and economically advantageous for the local people. For teachers, this activity provided them an avenue to engage in big-idea problems of energy and climate change. These direct personal experiences further increased the teachers' self-efficacy and confidence in teaching and learning engineering. Even the English language arts teachers seemed to be willing to extend engineering into their lessons.

In this process, an English teacher suggested to her group during the PD, "We could use Dragonwings [a historical novel by Yep, 2001] to connect windmill design and building with the events that happened in the novel." These authentic experiences were about change, which "involves learning, and...all change involves coming to understand and to be good at something new" (Fullan & Miles, 1992, p. 749). We observed that the direct experiences with STEAM disciplines and engineering in particular during the PD helped boost teachers' confidence in teaching STEAM. When the teachers taught both the water filter and the windmill activities in the regular classroom, they were more confident in engaging students in engineering design cycles as well as broader social, economic, and cultural questions that connected their community with STEAM.

Lesson 3: Inquiry as Access Point for Disciplinary Teachers Into the Engineering Process

Many of our teachers and leadership members were knowledgeable about inquiry teaching and learning but less comfortable with the engineering design process and methods. Many engineering problems are about finding the most cost-effective and useful solutions to make life better and easier. Our teachers were less certain about design steps and less concerned about problem-solving concepts. However, the university team and the leadership team wanted to tackle engineering processes through inquiry. We wanted the teachers to understand that the engineering design cycle they encountered in books and resource materials was another version of inquiry.

Engineering design involves distinct and overlapping steps: a problem or a question to be answered; thinking through potential and plausible solutions with the help from many sources, including home experiences; planning for both the process of finding a solution and a method of accomplishing tasks to solve the problem; building a workable model following the plan; and modifying the workable model or parts of the workable model so it functions better. These steps or ways of thinking are no different from inquiry teaching and learning because inquiry is also about asking scientific questions, researching for possible answers, planning and carrying out an experiment, and asking new questions to answer unanswered or partially answered questions. These connections helped teachers to make sense of engineering processes.

The university team engaged teachers in thinking about inquiry in social studies, English, music, arts, science, and mathematics. As one of the leadership team members stated, "There were many different ways of enacting inquiry, and design cycle was one of them with some substitutions." A teacher captured the sentiment of the entire STEAM teacher group when she stated,

> *"Just like in inquiry, we repeat the engineering design process in a problem-solving context where useful improvements in the designed product are always desired, and we learn new things with new improvements. In inquiry, we keep the process without a real stopping point."*

Many teachers found doing engineering and engaging themselves and later their students in engineering designs made them feel more comfortable. They now could envision doing engineering as they had been doing inquiry for so many years in their teaching careers. We asked teachers about their feelings about teaching STEAM and about their students. Table 1 shows greater comfort among teachers than what they had perceived in their students in the 1st year of their teaching STEAM.

Table 1
Frequency Responses on Understanding Integration of STEAM* by Teachers and Students
N = 30 (teachers); 188 (students)

Survey item	1 Not at all	2	3	4	5 Completely
Teacher understands how STEAM is more than the individual subjects.	0	3	4	17	14
Teacher believes students understand how STEAM is more than the individual subjects.	7	8	16	6	1

**Note:* STEAM = science, technology, engineering, arts, and math.

From the beginning, we understood that STEAM teaching and learning was about an integrated curricular approach to teaching STEAM disciplines. We also acknowledged that this was a superior approach to engaging students in 21st century skills and content, but we could not assume that the teachers would easily implement the new approach. For this, we created PD structures that allowed for teachers to learn new practices through hands-on and minds-on experiences, and later they implemented these activities and learning in their own classes. Direct experiences with feedback from the university experts helped teachers to reproduce success in their classrooms.

Lesson 4: Building STEAM Leadership Capacity

At the onset of our partnership, we understood that to successfully build and run a new STEAM school, the district had to build effective human capacity at both the classroom teacher and principal levels. At the new STEAM school, we conceptualized building leadership capacity in four ways:

1. Learning and constructing the meaning of STEAM for the school and the students was a collective and collaborative process between teachers, school administrators, and community members.
2. We generated ideas and solutions through innovative and new ways to improve STEAM learning experiences of students.
3. We generated shared beliefs and values around STEAM teaching and learning.

4. All involved continuously worked towards establishing communication for STEAM instructional improvement.

Through the two-year PD program and the supports provided during the first year of implementation of the STEAM initiative, the school built a very strong leadership framework through collective accountability. The teachers were constantly pushing students to engage in all content areas through unique activities that showed their collective responsibility to provide best learning opportunities to students through STEAM disciplines. For example, in one of the teacher meetings, the English teacher discussed how she "wanted to use various print media advertisements related to beauty products" where student would explore and discuss the merits of the products. To engage students in critical social and cultural issues, the teacher challenged them by asking, "If they were the inventors of the products, what would be their moral obligations in creating and selling the products?" The teacher groups agreed with the idea and brainstormed what products would fit this task in science, mathematics, social studies, arts, and engineering. The teachers had a collective sense of making this new idea work for the group and finding ways to make STEAM a much broader learning experience, not just engineering and science.

In another instance a music teacher wanted to create a production for the parents based on how air and water produced sounds. The teacher wondered what effects could be brought into this production from the STEM fields and what cultural values and traditions could come from diverse groups of student refugees, Native Americans, Hispanics, and other immigrant groups. Since students in the fifth grade were designing filters and students in the sixth grade were designing windmills, the theme on air and water in a musical production was fitting. The whole school had a week-long talk about how learning from other content areas was integrated into music, and parents were equally impressed by the collective sense of responsibility. The principal stated, "I am just amazed how much my teachers are part of the school and community. I like when someone other than me is taking the leadership initiative all the time."

What is important about the ways in which leadership was thought about and practiced in the STEAM school is that the leadership was not a single person's trait but a sense of collective progress. As everyone at the school was seeking to teach STEAM through an integrated curricular approach, a common goal was collective success. Without a broad sense of leadership, the success of the STEAM school would not have been possible.

Discussions and Implications

Successful STEAM university–school partnerships influence positive change in pedagogy and content, supporting learning for diverse groups of students (Darling-Hammond & Lieberman, 2012). University–school partnerships become successful when mutually agreed-upon, common goals are built through prolonged relationships (Kruger et al., 2009) and hierarchical barriers between university and school are removed (Zeichner, 2010). Therefore, our approach to a university-school partnership experience showed that building a STEAM school had to come from the local schools, the teachers, and the school administrators. Our finding related to successful partnerships for STEAM education supports similar findings where stakeholders both valued and knew each others' role and were clear about goals and aspirations (Ure et al., 2009). As our partnership was based on coequal roles, our engagements before, during, and after the PD showed "nonhierarchical interplay" (Zeichner, 2010, p. 89). This allowed us to develop and engage in an integrated curricular approach to STEAM teaching and learning situated in the local school with local input and support systems.

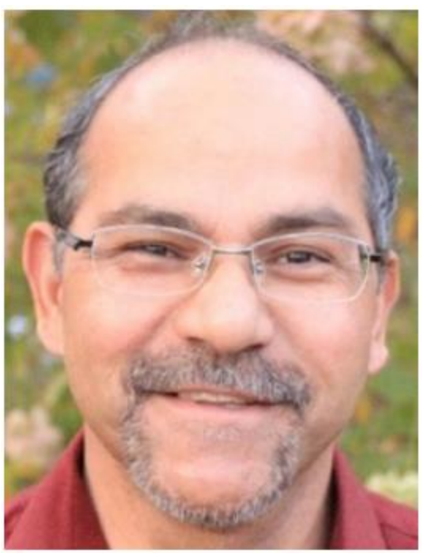
We also found that for changes to occur in the areas of STEAM teaching and learning, teachers and school stakeholders have to have direct experiences in content and pedagogy so they can implement change effectively in their classrooms. Studies have shown that many elementary school teachers experience impediments in science because of lower depth in content and lack of resources for effective inquiry teaching and learning (Goodrum et al., 2001; Kenny, 2010). Therefore our partnership provided needed opportunities for teachers to learn and become familiar with some activities and content to build confidence in STEAM teaching and learning. Engineering design and related activities were areas of great concern for the teachers because they did not have a degree in engineering and had not received PD in engineering. The teachers felt anxious about teaching engineering practices and designs in an integrated STEAM environment. Our finding is similar to studies showing similar results where K-12 teachers were least sure about teaching engineering to their students (Haverly, 2018; Trygstad, 2013).

A major rationale given to policy and curricular initiatives in favor of STEM/STEAM education has been to build a citizenry with critical thinking, communication, curiosity, complex thinking, compassion, and collaboration skills (National Research Council, 2011; National Science Board, 2010). The teacher and school leaders felt that stressing the 3Cs would improve academic success in all content areas and also support students to connect STEAM content beyond school classrooms. Furthermore, the results showed that integrated STEAM education in this school helped develop many dispositions connected to the 3Cs. The STEAM integration helped students develop habits-of-mind more readily and sustainably. Yet, the results showed less growth in the 3Cs in music and arts. It is concerning in that students did not seem to link habits-of-mind skills to non-STEM areas. However, the design labs, being a part of engineering, showed less growth. We think this is because design labs are new to students and they had not encountered it before in their schooling. We anticipate students showing improvements in 3Cs once they get more acquainted with the discipline in the fifth and sixth grades.

Similarly, as the teachers received direct hands-on and minds-on experiences in STEAM, specifically engineering, they felt more comfortable with STEAM as a cohesive idea. However, we found students may need more time to feel comfortable with the idea of STEAM so need more frequent engagement with this pedagogy. Finally, without building a robust and dedicated team of STEAM teacher leaders, a STEAM education initiative is not likely to succeed

(National Research Council, 2011). STEAM teacher leaders can influence both the pedagogy and content of STEAM teaching and learning in the school. For example, the STEAM teacher leaders in this partnership led group interactions during the PD and helped build STEAM goals and school implementation plans. Research continuously has shown that when school leaders (principals) and teacher leaders guide and provide support to peers for change, the success rate of any kind of school change initiative improves (Bryk et al., 2010). Furthermore, in our STEAM university-school partnership, we were deliberate in being inclusive of all the stakeholders and their voices so everyone embraced the change and activities related to that change. Hence the STEAM leadership team we built through the partnership became successful in leading the STEAM school and were willing to adjust based on diverse student and teacher needs.

This university–school partnership had some challenges in what STEAM education should look like for the community, teachers, and the school district. Many of the challenges were because of the novelty of STEAM education at that time and the shortage of STEAM teacher leaders who would support and navigate this change in everyday classrooms. Furthermore, in an increasingly diverse classroom, the challenges remained as to who should address these challenges and how as integrated STEAM education takes off. A key reason for the success of this university–school partnership was a relationship built on mutual respect, trust, and being coequal partners for change that was based on local school contexts and needs.



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Introducing Golden Section in the Mathematics Class to Develop Critical Thinking from the STEAM perspective

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Abstract

The Golden Section is a mathematical concept that is one of the most famous examples of connections between mathematics and the arts. Despite its widespread references in various areas of nature, art, architecture, literature, music, or aesthetics, discussions of the golden ratio often turn out to be false or misleading. Most of the incorrect statements are based on approximations or stem from the lack of checking the facts, making scientific mistakes in verifying the original scientific, historical, cultural context, or performing arbitrary operations in the measurements. This article offers geometric data and measurements, which allow the students to explore the golden ratio in various contexts through problem-solving activities. At the same time, we encourage students and their teachers to initiate critical discussions based on multidisciplinary research in the areas of STEAM about their findings. Such research-based critical discussion can help to discover the context of their results from several other perspectives in addition to mathematics. It can also reflect both the cultural and scientific validity of the - otherwise mathematically correct - computations, as an essential expectation towards mathematics applied in a cultural or social context. For some of the topics described in this paper, we provide GeoGebra applets, which can let the reader explore the phenomena, and some pedagogical usage in classroom may yield examples for various populations of students. The topic is valuable in STEAM Education, with activities relying on European, Southeast Asian and Middle Eastern perspectives.

Keywords: Golden Ratio, STEAM education, Dynamic Geometry, cultural background

This article offers an introduction to the various appearances of the Golden Section in various fields of sciences and the arts. We selected examples from our own research and pedagogical experiences and offer an outline of how these Golden Section examples can be utilized in classroom teaching for motivating students and offer opportunities for research extended to all STEAM areas and initiating critical discussions on cultural topics in the mathematics class.

In general, we would like to introduce Golden Section as a topic, which holds several learning opportunities in upper secondary mathematics education in mathematical problem-solving. At the same time, learning about the Golden Section can be a great opportunity to debunk erroneous or mystical interpretations and start to think critically about the cultural role of geometric data and measurements. The choice of the points for measurement has an influence on the result and the measurements and computations often provide approximations of the Golden Ratio, not always an exact value. This paper is devoted to STEAM education, with a special emphasis on Technology, Arts and Mathematics connections, i.e., technology-assisted mathematical activities around artistic artefacts. Its main goal is to propose mathematical activities, which can be based on topics from the cultural background of the students, hence the variety of examples in the paper.

In addition, we would like to highlight the important connection between mathematics and arts as well as the interconnectedness of various fields in science to be able to offer a transdisciplinary way of learning. Furthermore, we developed all examples with technology files and enable readers to explore Golden Section with interactive worksheets created by the open-source mathematics software GeoGebra1. This offers various possibilities of activities in STEAM education. In the following sections, we will offer an introduction to Golden Section and then offer a variety of examples from a wide range of fields: within mathematics (with an example from trigonometric functions), music, the structure of musical instruments, geography (with an example inciting students to learn some spherical trigonometry), etc.

The Golden Section

An ancient question is "How can we divide a line segment into two segments in a harmonious way?" One answer is to divide it into two parts of equal length. Another answer has it that harmonious proportions can be obtained as follows (Figure 1).

Figure 1
Harmonious Division of a Segment

Denoted by *a* and *b* are the respective lengths of the segments AB and BC. These numbers should verify the following equation:

(1) $$\frac{a+b}{a}=\frac{a}{b},$$

i.e., the ratio of the total segment length over the largest sub segment is equal to the ratio of the two sub segments. This equation can be written as $1+\frac{b}{a}=\frac{a}{b}$. Now denoting $\varphi=\frac{a}{b}$, then Equation (1) is equivalent to

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(2) $$\varphi^2-\varphi-1=0.$$

Equation (2) has two solutions; only one of them is positive, namely $\varphi=\frac{1+\sqrt{5}}{2}$.

As $\sqrt{5}$ is an irrational number, ϕ is an irrational number too. A decimal development of ϕ is $\varphi\approx 1.618033988$.

Among the numerous mathematical properties of the number ϕ, we will mention a few:

- It has a surprising connection to the integer 5: $\varphi=\sqrt{\frac{5+\sqrt{5}}{5-\sqrt{5}}}$.
- It is equal to the simplest continuous square root: $\varphi=\sqrt{1+\sqrt{1+\sqrt{1+\sqrt{1+\ldots}}}}$
- It is equal to the simplest continuous fraction: $\varphi=\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\cfrac{1}{1+\ldots}}}}$
- Its powers generate copies of the Fibonacci sequence[2]:

$$\varphi^2=1+\varphi$$
$$\varphi^3=1+2\varphi$$
$$\varphi^4=2+3\varphi$$
$$\varphi^5=3+5\varphi$$
$$\varphi^6=5+8\varphi$$
$$\varphi^7=8+13\varphi$$
$$\ldots$$

The number ϕ has been called the Golden Section, sometimes the Divine Proportion. A rectangle whose length a, and width b verify the condition is called a Golden Rectangle. This

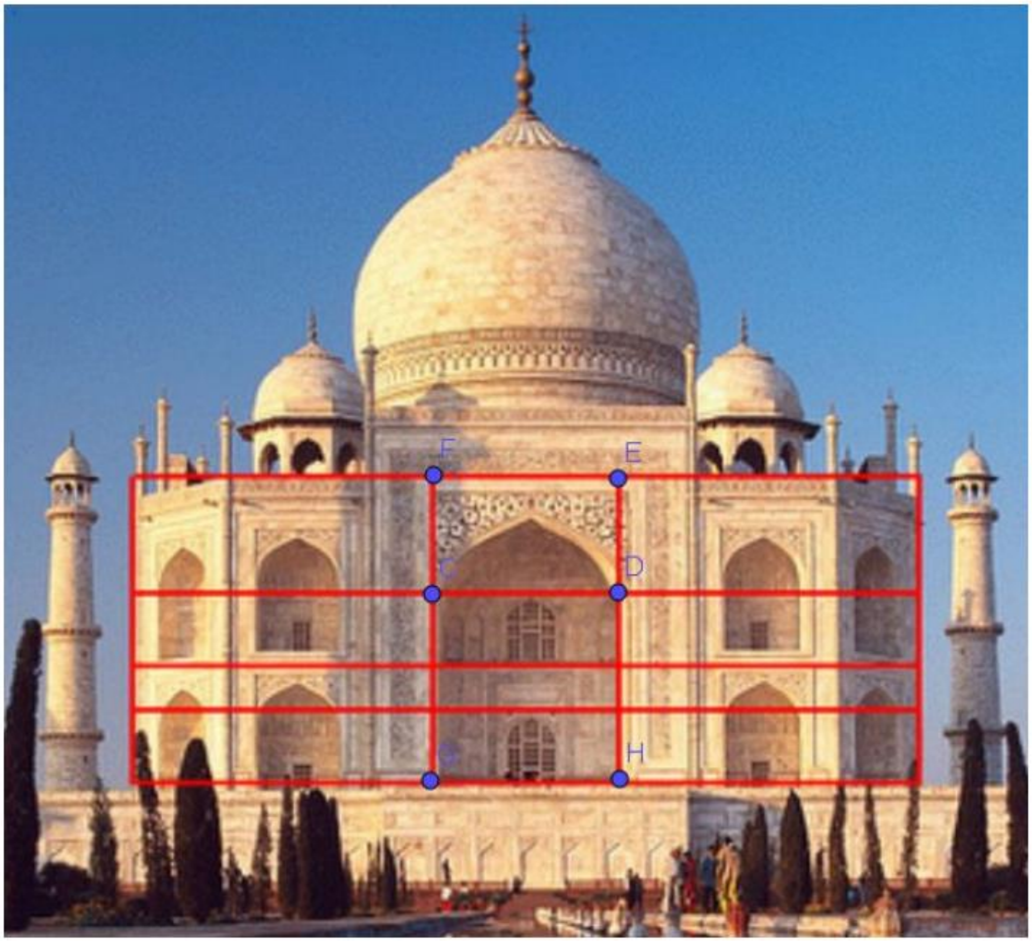
Divine Proportion name was first used by Fra Luca Bartolomeo Pacioli, a Franciscan monk, in his book De divina proportione (illustrated by Leonardo da Vinci)3.

The Golden Section became one of the most popular examples of connections between mathematics and the arts. Despite its widespread references in various areas of nature, art, architecture, literature, music, or aesthetics, discussions of the golden ratio often turn out to be false or misleading. Articles from Markowsky (1992), Gardner (1994), or Falbo (2005) serve as good guidance to study this famous geometrical proportion, but assess critically such photographs, which introduce, e.g., the main façade of temples in ancient Greece as golden rectangles, i.e., a rectangle whose length L and width l verify the condition $L/l=\phi$. The most famous example is the Parthenon on the Acropolis in Athens (see Figure 2). Actually, the rectangular part of the façade with the columns is not a golden rectangle, but the rectangle enclosing the whole of the façade is often depicted as such.

Figure 2
The Parthenon

Golden rectangles are often introduced as construction principles in other famous monuments as well, such as the Taj Mahal in India. Figure 3 shows a snapshot of a GeoGebra session to inscribe some golden rectangles in this monument and discuss the role of the photographic perspective and other variables in locating such proportions. We emphasize that this is a way for students to use GeoGebra as an exploration tool, sometimes using its features for augmented reality (AR).

Figure 3
Using GeoGebra to Project Golden Rectangles on a Photograph of the Taj Mahal



Similar kinds of technology-based activities can be developed to assert occurrences of Golden Rectangles in other monuments. As we will see in the next section, the number ϕ can be studied in relation to other ancient objects and monuments. For more examples, see Dana-Picard (2017), Frantilli et al. (2011), and numerous websites.

The Golden Section in the Bible: Objects

Noah's Ark

The dimensions of Noah's Ark are given in the verse Genesis 6, 15: " And this is how thou shalt make it: the length of the ark three hundred cubits, the breadth of it fifty cubits, and the height of it thirty cubits".

Figure 4
Noah's Ark (1846), by Edward Hicks

The ratio of the breadth to the height is $\frac{50}{30} = \frac{5}{3} \approx 1.667$. This is obviously not the Golden Section, but it is an approximation of φ to one digit after the decimal period.

The Ark of the Covenant

The order to build the Ark of the Covenant (the cabinet containing scrolls of the Torah, written by Moses) is given in the following Biblical verse (Exodus 25, 10)5: "And they shall make an ark of acacia-wood: two cubits and a half shall be the length thereof, and a cubit and a half the breadth thereof, and a cubit and a half the height thereof." Figure 5 shows a reconstitution of the Ark with the cherubim (angels) on top. The dimensions indicated in the verse are those of the rectangular box, excepting the staves. The side faces are rectangles with respective length and width of 2.5 cubits and 1.5 Cubits

cubits. Their ratio is $\frac{2.5}{1.5} \simeq 1.667$, the same approximation as above of the Golden Section[6].

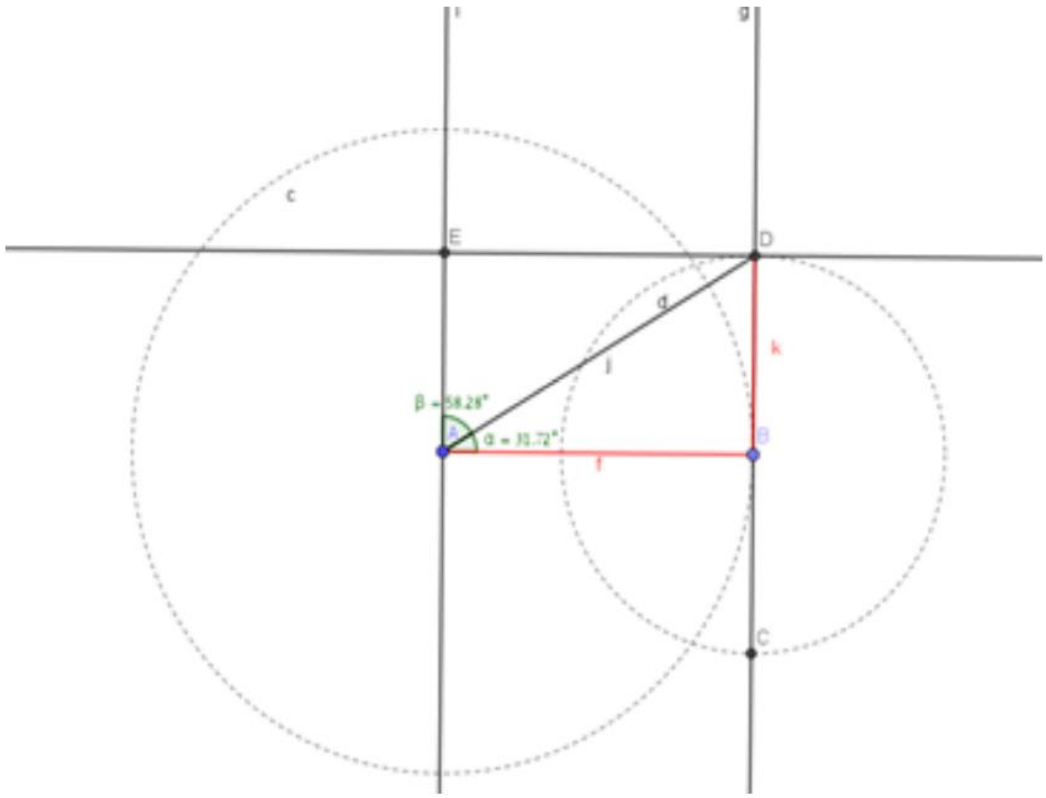
Figure 5
The Ark of the Covenant

Students' discussion of these examples can assess the role of approximation in applications of mathematics.

Example: Jerusalem

Figure 6 shows a snapshot of a very easy GeoGebra session for the drawing of a golden rectangle.

Figure 6
Drawing of a Golden Rectangle with GeoGebra.



In an experimental way, this drawing provides a value of the two angles defined at each vertex of the rectangle by the diagonal exiting this vertex. Of course, a high school student should be able to compute these values using basic trigonometry. Here we have: α=31.72° and β=58.28°. Note that:

- The number 31.72 is the latitude of Jerusalem and $\cot 31.72^o = 1.618$
- The number 58.28 is the culmination of the Sun (zenith) during the equinoxes in Jerusalem.

We can discuss with the students that it is hard to check the precision of these numbers, as the City of Jerusalem is a large area, so the question can be to which point in the town do these coordinates relate? It is worthwhile to discover and examine the assertion of various website authors who describe other connections between Jerusalem and the Golden Section. They are out of the scope of this paper, and sometimes they are based on inaccurate latitude-longitude coordinates.

The Golden Section: Measurements and the Pentagram

Consider a regular pentagon whose side length is equal to 1. An easy computation for the students shows that the (common) length of the diagonals is equal to ϕ. Figure 7 shows a snapshot of a GeoGebra session to check this experimentally:

- Draw a segment AB of length 1;
- Draw a regular pentagon, AB being one of its sides;
- Draw the diagonals of this pentagon. The non-convex polygon formed by the diagonals is called a Pentagram.

The notations l, m, n, p, and q represent both the diagonal segments and their respective lengths; note that in the left column (called the algebraic window), they have a common value 1.618. We wish to make the following remarks:

- The accuracy of the approximation can be improved when requesting from the software to display more digits after the decimal period.
- When requesting from the software to display the object details, then the definition of q, for example, is Segment (C, A).

Now, compute the ratio of some of the segments. First, we obtain experimentally:

$$\frac{DB}{AB} = \varphi$$

Denote by F the point of intersection of the diagonals EB and AC. Then we have:

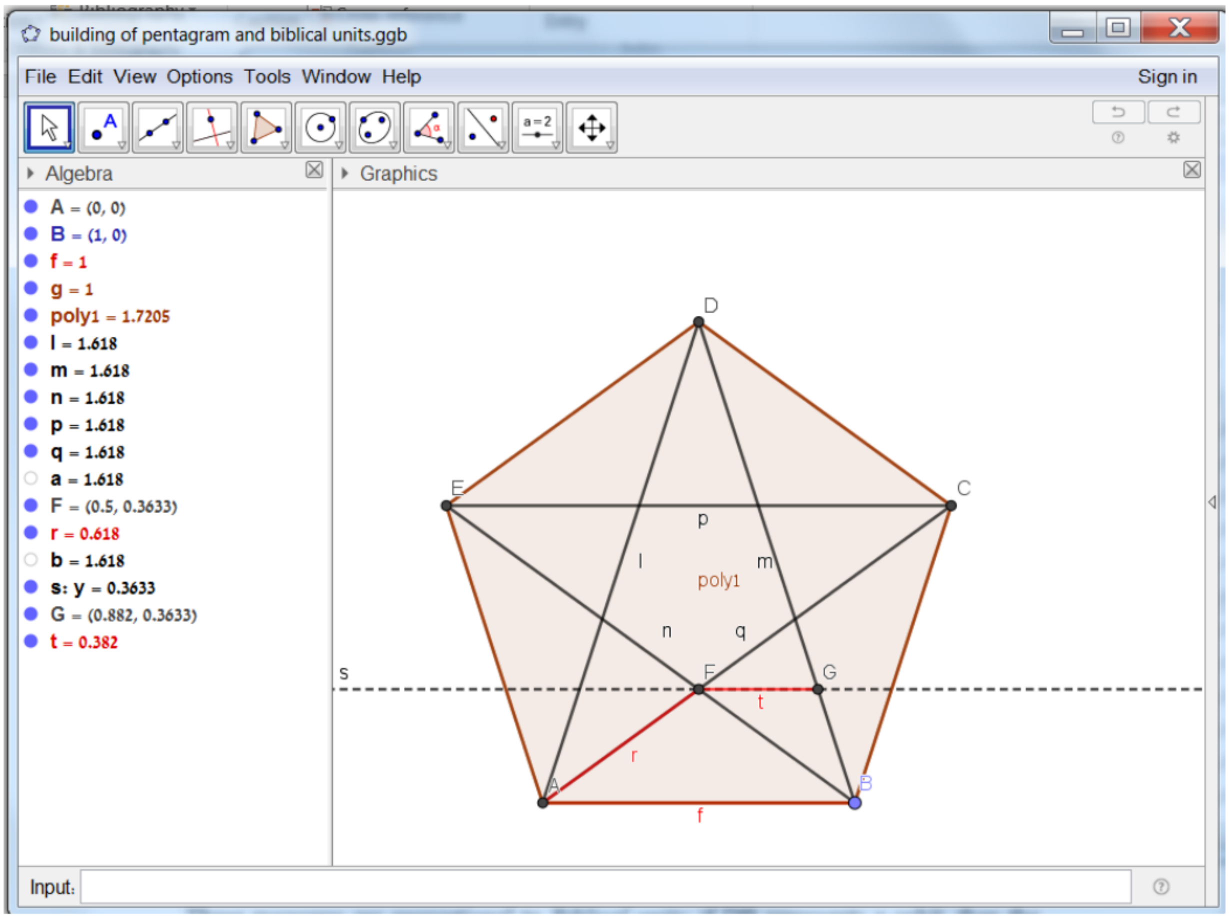
$$\frac{AB}{AF} = \varphi$$

Denote now by G the point of intersection of the parallel to AB through F. We have:

$$\frac{AF}{FG} = \varphi$$

Of course, this experimental discovery can be (and has to be) followed by exact computations, using trigonometry.

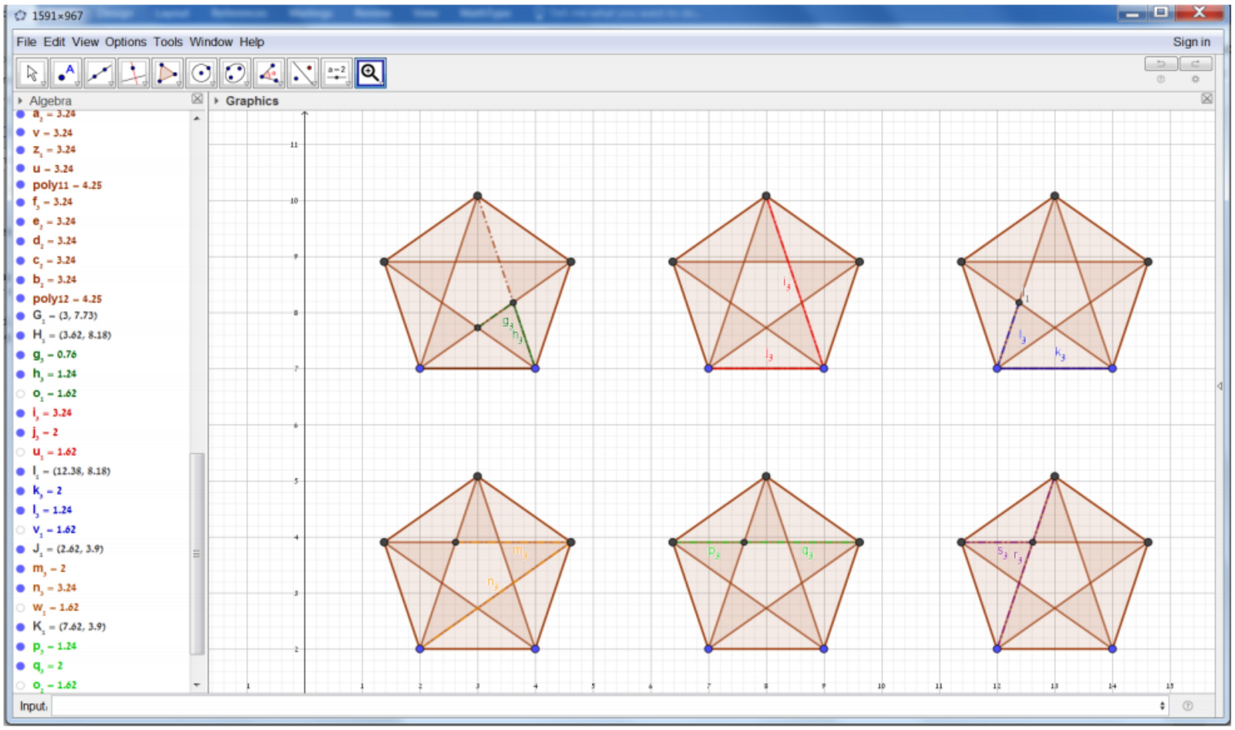
Figure 7
Building a Pentagram with GeoGebra



These measures are proportional to Biblical length units: if DB represents a cubit, then the following segments will represent a foot, a palm, etc.

Numerous other proportions of segments defined by the pentagon and the Pentagram and involving ϕ are illustrated in Figure 8. This is a snapshot of a GeoGebra session to check different ratios experimentally. For every pair of segments, the computer input and result appears in the left column (algebraic window).

Figure 8
Golden Ratios in Pentagrams shown with GeoGebra



Octagonal buildings
The Castel del Monte, Italy

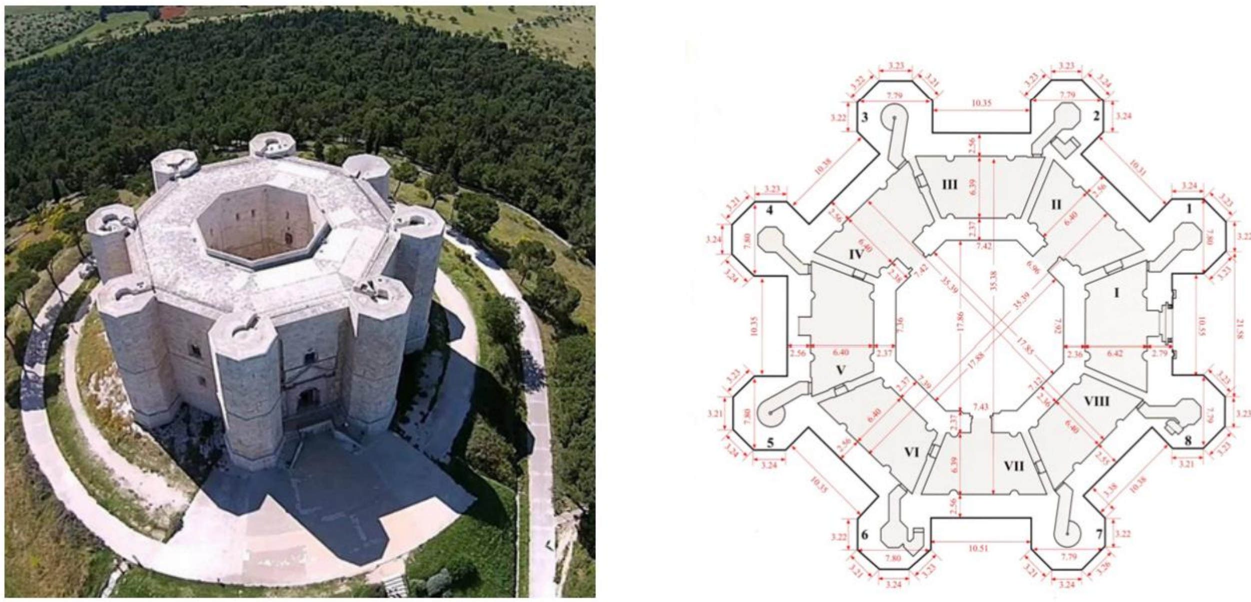
Castel del Monte was built by Emperor Frederick II on top of a hill in Apulia in Apulia (Southern Italy). It is shaped by several octagons. At first glance, Golden Rectangles may appear, as shown in Figure 10 (the main entrance). Once again, students can use GeoGebra as a tool for exploration. The students can check the details of Golden Rectangles with accuracy.

Figure 10
The Main Entrance to Castel del Monte

Now, let us look at the general structure of the castle. The main part is a ring enclosed by two concentric regular octagons (see Figure 11). The interior part of the smaller octagon is an open sky yard. At each vertex of the exterior octagon is an octagonal tower. We will focus on the main building.

Of course, the castle is divided into halls and rooms, as displayed in Figure 11b. Students can import the map as background of a GeoGebra session and re-build the map. The students can then check that the halls shaped as trapezoids (numbered with Roman numerals I-VIII in Figure 11b) have the following remarkable property: the ratio of the long base measurement over the short one of each of these halls is equal to ϕ.

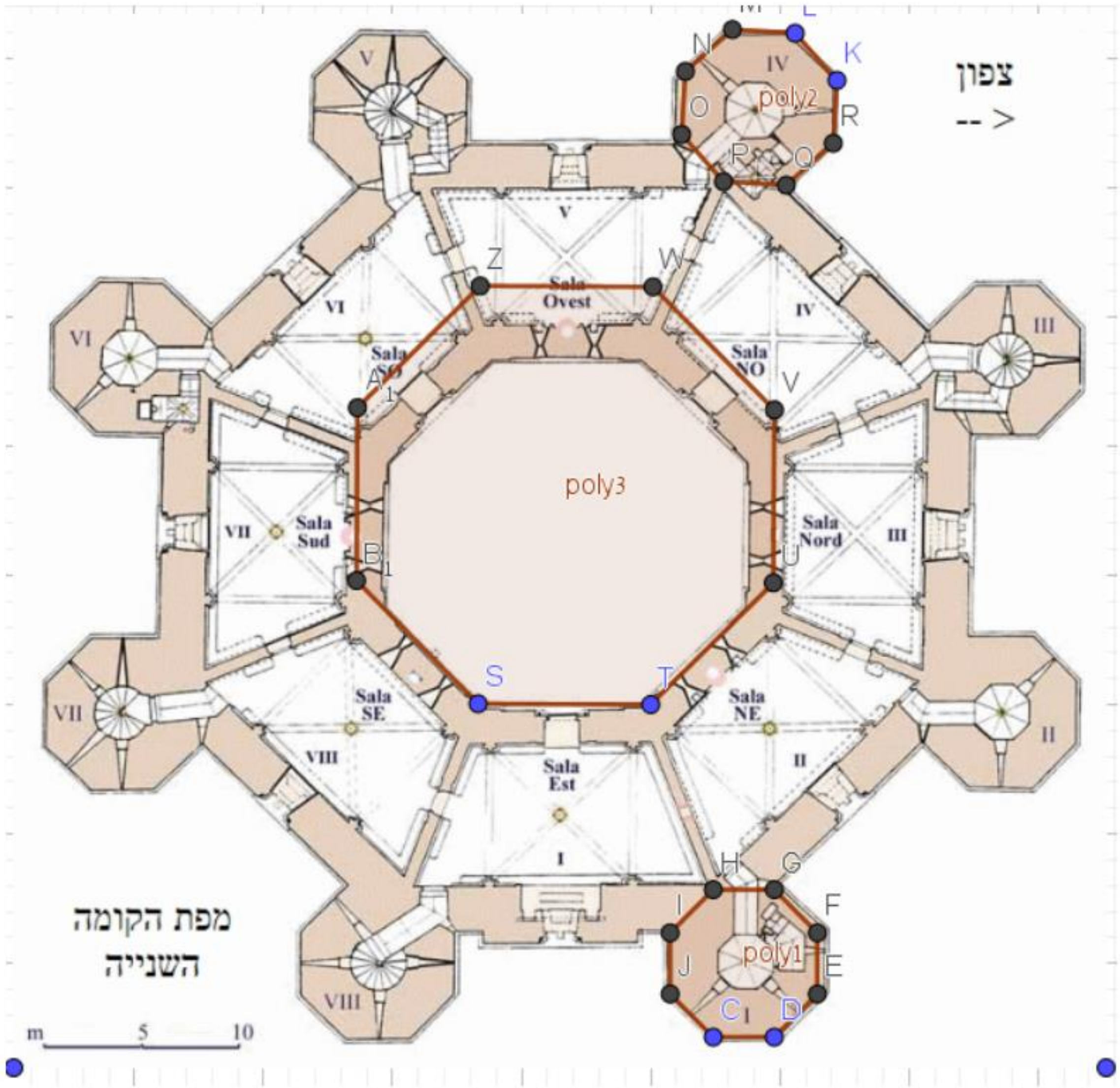
Figure 11
The Castel del Monte



(a) Aerial view (b) Map with measurements

All of these halls have the same dimension because of the numerous symmetries of the building. Dana-Picard and Hershkovitz (2018) give details of a classroom activity for this. Remark: the actual measurements presented in Figure 12 have been obtained by Götze (1998). There exist other maps, with different focus of interest. Automated creation of regular polygons with GeoGebra enables us to check that the octagonal shapes of the castle are not actual regular octagons; such deviations are clear in Figure 12.

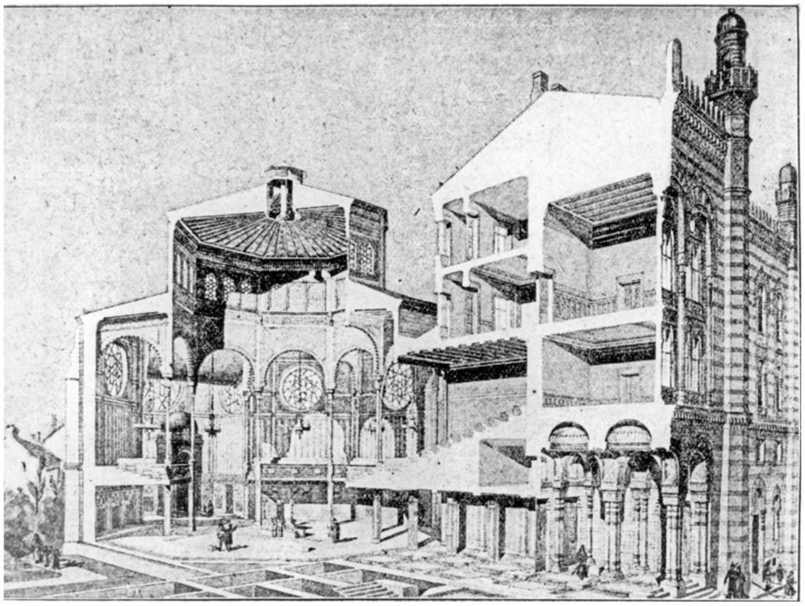
Figure 12
Checking the Regularity of Octagons



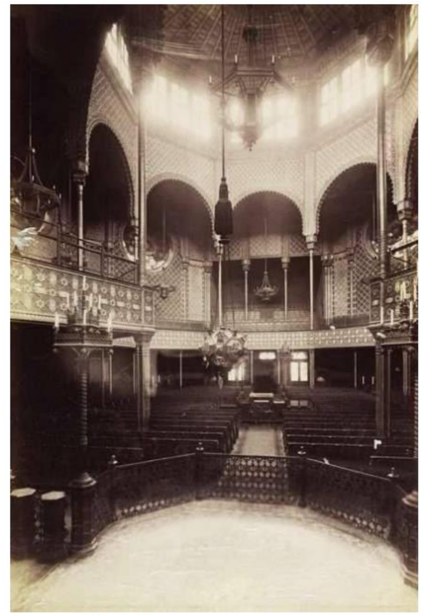
The Rumbach Synagogue, Hungary

We look now at a 19th century synagogue on Rumbach Sebestyén street, Budapest. It was built on a piece of land enclosed in a non-regular polygon. The architects planned a building in which we can distinguish two different parts (see Figure 13a): one of them is divided into an apartment and classrooms; the other part, the westernmost, is an octagonal synagogue.

Figure 13
The Rumbach Synagogue, Budapest



(a) Drawing by the architect Otto Wagner, 1869

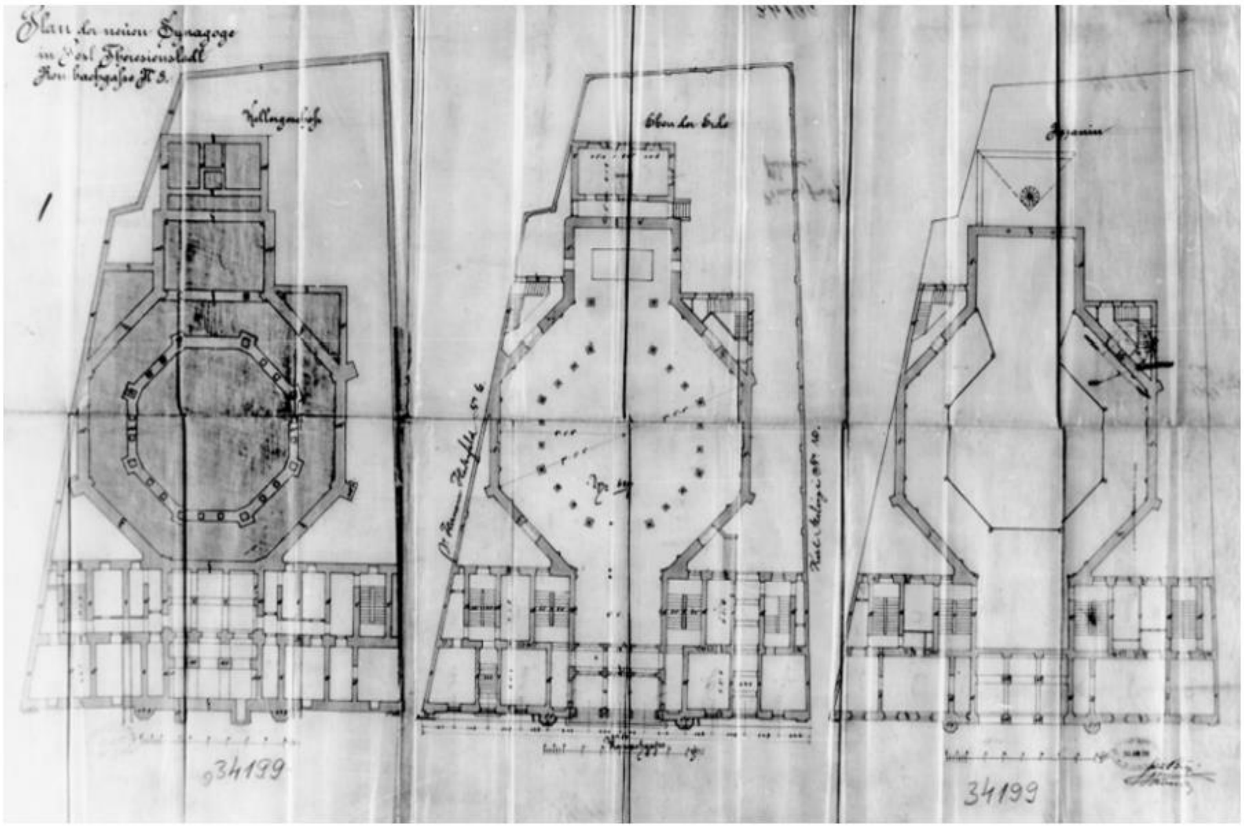


(b) The synagogue in 1895

In Figure 13b, a photo from the year 1895 is displayed. This is a view from the center of the prayer hall in the direction of the entrance. This explains the fact that in Figure 13a, on the right, the octagon is not complete, one of the missing sides being a side of an external rectangle. Symmetrically, the same phenomenon occurs on the opposite side, where the "Holy Ark" containing the Torah (the Pentateuch, or the Five Books written by Moses on Mount Sinai) scrolls is situated.

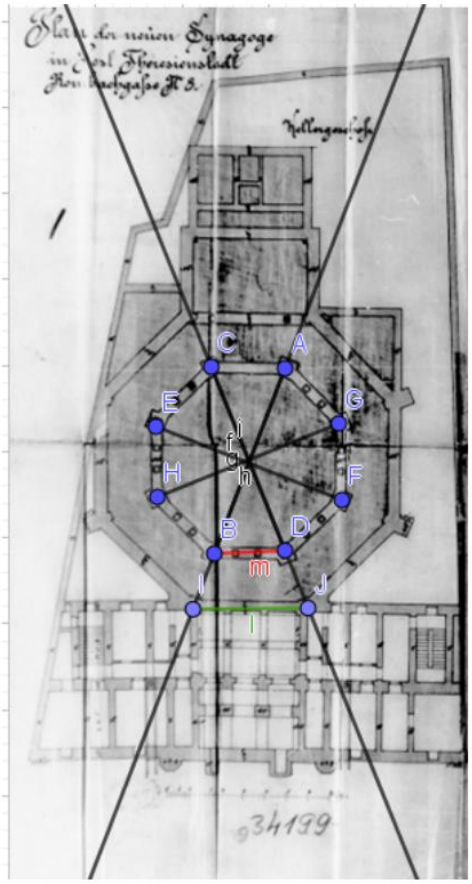
Figure 14 shows the original plans. On the left is the plan of the women's gallery (Two floors above the men's prayer hall (ground floor, on the right). Two concentric octagons are apparent: the external one for the walls, the internal one is actually not full. The last one is made of separate columns, which bear the women's gallery, visible in the plan on the right.

Figure 14
The Original Plans of the Rumbach Synagogue



Students can perform the same exercise as in the previous section, using the augmented reality (AR) features of the software in order to check the proportions of the building (see Figure 15). Augmented reality applications are already used in GeoGebra and there are numerous efforts to experiment with AR in teaching mathematics and other related topics. We are currently running some experiments with AR and will report this in future papers.

Figure 15
Golden Proportions in Rumbach Synagogue



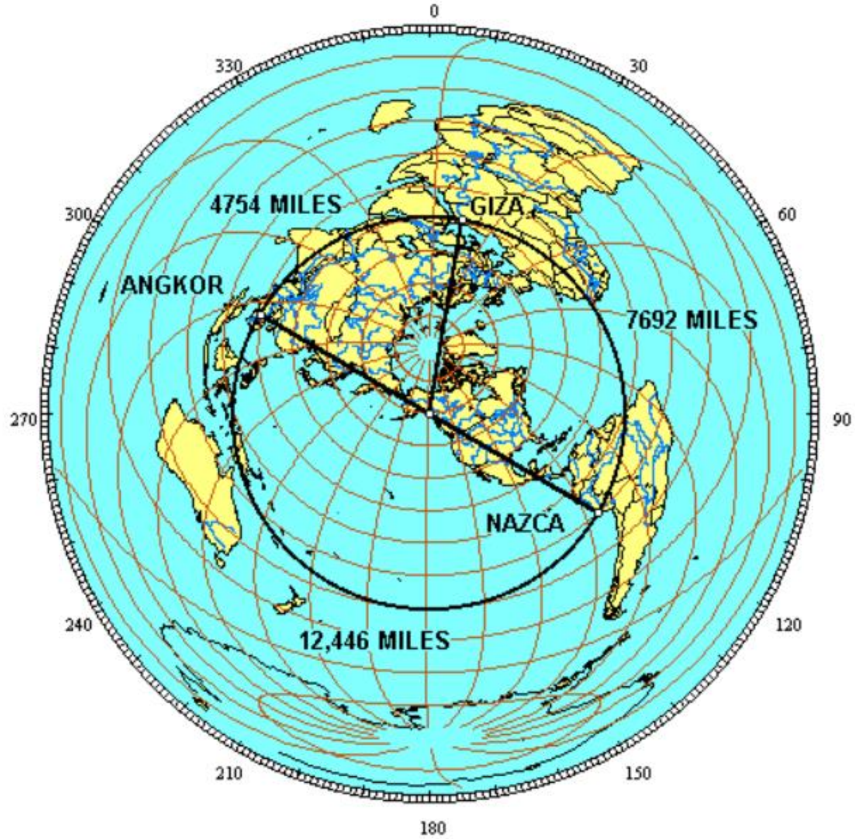
The columns supporting the women's gallery are not connected by walls and the whole of the volume on the three floors is open. Nevertheless, if students draw the diagonals through the center of the octagon, they define trapezoids whose bases are external walls (long bases) and the "virtual" segments between columns (short bases). An experimental checking using the software shows that the length ratio of the bases is equal to.

Angkor Wat and the Giza Pyramids

Angkor Wat was originally constructed in the early 12th century by the Khmer King Suryavarman II in what is now Cambodia. Several strange numbers arising from the monument, sometimes related to space measurements are given by Spivey (2016).

The shortest distance between two points, A and B, on a sphere is measured along an arc of a great circle, namely a circle passing through A and B and whose center is the center of the sphere (Jennings, 1994, Chap. 2). There exists a single great circle through Angkor Wat and the Giza plateau, with its pyramids. The distance from Angkor Wat to Cheops pyramid is equal to 4,754 miles. If a point, A, were to denote the location of Angkor Wat, then the second endpoint of the diameter of this great circle is situated 35 miles northwest from the Peruvian city of Nazca, where an outstanding archeological site is located.

Figure 16
The Great Circle: From Angkor Wat to Cheops Pyramid



The distance from Cheops Pyramid to one of the main sites in Nazca is equal to 7,692 miles. Note that 7,692 = 4754*1.618005889, a 4-digit accurate approximation of the Golden Section. This can be an excellent problem-solving analysis challenge for students.

There are other ancient sites either on this great circle or close to it. For example, Preah Vihear in Cambodia and Passover Island, are on the circle. Petra and Persepolis are within 10 kilometers. They are listed on a website dedicated to Machu Picchu. Their relation to the Golden Section has still to be studied. Students can explore these structures and their relationships on the great circle mentioned.

We propose a canvas for some classroom activities:

- Import a suitable picture such as the background of Figure 16 as a background for a GeoGebra session.
- On this background, plot the points corresponding to the monuments under consideration.
- Plot the circle through these points. Interaction using the mouse may be highlighting.

- A nice challenge for the students: find new monuments/traditional sites close to the circle.
- Checking with the DGS the distance from these sites to the great circle may provide an opportunity to check the importance of approximations in applied situations.
  More advanced students may have the benefit of this example to broaden previous knowledge about spherical geometry, as explained by Jennings (1994). We emphasize that this is especially important for applications.

Calendars

This section is also based mostly on approximations and has multiple goals:

- Computations are based mostly on approximations. The topic yields another opportunity to assess the role of approximations.
- The topic under study is always seen as purely geometric. We show here a more abstract occurrence of the Golden Section. Other abstract situations exist; they will be the topic of further work.
- The connection between concrete objects (planets and their motions) and more abstracts notions (time) can be highlighted. An extension towards history of the students' traditional calendar is natural.

Numerous calendars are used in the world. Generally, the best known are the Gregorian calendar, the Muslim calendar, the Buddhist calendar, and the Jewish calendar.

Several definitions of a *solar year* exist, dependent on the astronomical phenomenon taken as a reference. For example, a *sidereal year* is the time such that, when observed from the Earth, the Sun is at the same position with respect to the stars on the celestial sphere. The *Gregorian calendar* is solar. One such year is the time interval of two passages of the Earth at the same point on its orbit around the Sun. It is computed so that the spring equinox is as close as possible to the 21st day of March. The length of a Gregorian year is 365.256363051 days (i.e., 365 days 6 hours 9 minutes and 9.767 6 seconds). Because of the fraction of a day (the digits after the decimal period), a correction is needed and an extra day is added every 4 years, but every 100 years this extra day is not added.

A lunar calendar is based on lunar months. One *lunation* is the interval between two *new Moons*. It is approximatively equal to 29.53058885 days. The Muslim calendar is lunar, i.e., fully based on the Moon.

Figure 17
The Phases of the Moon along one Lunation

The two kinds of calendars have very different features. In a solar calendar, the notion of year is meaningful but months are arbitrary. In the lunar case, the notion of a month is (almost) well defined, but the notion of a year is arbitrary.

The Jewish and Buddhist calendars are lunisolar, i.e., they take into account both astronomical phenomena. The notion of a year is important, but the basic unit is the lunar month. As one lunar month is not made of an integer number of days, the equilibrium is made in the Jewish calendar by using months of 29 days alternating with months of 30 days. Two of the months may have either 29 or 30 days (separately) according to the specific year (The Buddhist calendar, which is based on lunar cycles within a sidereal year, is still used for religious observances, while the official governmental calendars are Gregorian, thus religious observances fall on different days each [Gregorian] calendar year).

Twelve such months are not synchronized with a solar year: there is a gap of 12 days. This is compensated when adding a 13th month from time to time. How is this performed?

The Greek astronomer Meton of Athens observed that 19 solar years (i.e., 19 x 365 days) correspond (almost) exactly to 235 lunations. This corresponds to 6,940 days, with an error of a few hours. With this approximation, Meton obtained that 125 long months (30 days) and 110 short months (29 days) were needed for his calendar.

Actually, concerning years, the following formula, known as *Meton's formula*, holds:

$$12 \cdot 12 + 7 \cdot 13 = 235$$

In other words, in a cycle of 19 years, take 12 years with 12 months each and 7 years with an intercalary month (a 13th month), and this performs the needed synchronization. A 13-month year is called embolismic.

This is the way the Jewish calendar is built: 12 years of 12 months each and years 3, 6, 8,11,14,17, and 19 of each cycle are embolismic.

Meton noted that if we were to share the 6940 days equally between the 19 years, we would obtain 365 + 1/4 +1/76 days. This reinforces the need for embolismic years. He noted that the proportion of years in each lunation is given by: 19/235 ≈ 0.0809. By denoting this number as α, we have: α ≈ 0.0809, 2α ≈ 0.1618 ≈ ϕ/10, … 20 α≈ϕ.

Based on this, we can make a thought experiment on the approximation to a mathematical concept, i.e., the Golden Proportion, which we understood to be a geometric characteristic, that it can be projected to time.

Further connections

The *Fibonacci sequence*[19] is defined by $\begin{cases} F_1 = F_2 = 1 \\ F_{n+2} = F_{n+1} + F_n, n \geq 1 \end{cases}$. It is generally presented to students as a first example of a sequence defined with an induction formula using two terms to determine the next one. This is feasible with junior high school (lower secondary/middle school) students.

It is connected to the Golden Section by the following property: $\lim_{n \to +\infty} \frac{F_{n+1}}{F_n} = \varphi$.

The notion of the limit of a sequence comes later in the syllabus, therefore activities connected to the ratio of two consecutive elements of the Fibonacci sequence as an approximation of the Golden Section can appear only later.

Practical applications of the mathematical notions are of the utmost importance for many students. The Fibonacci sequence appears in numerous cases, some of them are handcrafted such as Judaica objects; others exist in nature, such as various flowers. These have already been described on many occasions. For specific groups of students, it may be interesting to look after occurrences of elements of the Fibonacci sequence in the monuments described in the previous sections. For example, the authors found all of the first nine elements in the Rumbach synagogue in Budapest. (See also Dana-Picard and Hershkovitz [2018]). Finding Fibonacci numbers when counting architectural elements is purely descriptive, thus accessible to any age. Nevertheless, the computations in the “Octagonal Buildings” section and the Dynamic Geometry System based activities can be proposed only after some geometric background has been acquired (See Dana-Picard and Hershkovitz [2019]).

The geometric and trigonometric aspects of our study address students of different ages. With basic knowledge of trigonometry, the study of the various ratios in regular pentagons and pentagrams is accessible. The next example, in “The Golden Section: Measurements and the Pentagrams” section, is aimed at more advanced students, as it requires acquaintance with the arcsine function.

The part of our study devoted to astronomy requires at least some interest of the students for this kind of topic. The numerical data are available over the web; it is the educator's duty either to provide the data or to guide the students for their web search.

Computations for the Hebrew lunisolar calendar involve more details than what we presented in the “Calendars” section. Nevertheless, they are accessible already in primary school. A colleague of the authors teaches this topic to 5th grade students. Figure 18 shows an activity proposed by the second author to such students.

Discussion

In this paper, we offered a variety of examples for critical discussion on the Golden Section together with interactive resources and suggested some uses in education.

We believe that using some of these examples for developing students’ abilities for critical explorations and debunking myths and understanding the role of approximation in mathematical applications could offer motivation for learning and could enable teachers to engage in interesting learning experiences. We hope that this paper also offers motivations for others to develop further examples within this topic and/or explore other mathematical ideas with technology and in relation to the arts. We believe that transdisciplinary learning, often highlighted in STEAM education could become a powerful approach in education.

The examples offer new perspectives to explore cultural phenomena. We are planning to develop further examples specific to Asian cultures and would like to encourage teachers and researchers in the various Asian regions to examine possible uses of local arts and culture for STEAM education. We would like to use these examples to use with further teaching and learning of mathematics and other STEAM subjects in a transdisciplinary matter thus enriching classroom activities and offering new ways to engage and contribute to students’ learning. Furthermore, Dana-Picard and Hershkovitz (2019) showed how to use examples from the cultural background of students. They developed activities for exploration with a Dynamic Geometry System of Jewish monuments and their geometric properties, aimed at a specific student population. With the examples described in the “Calendars” section, we show that this point of view can be suitable for other students, building activities on each student’s cultural background.

Thierry (Noah) Dana-Picard has been involved for more than 30 years in teacher training, both pre-service and in-service. He has served as head of the mathematics department in different Teacher Training Colleges. Later, he chaired the department of mathematics of the Jerusalem College of Technology (JCT), an academic institution training engineers in high tech. Since 2013 Professor Dana-Picard has been president emeritus of JCT, and director of a research chair. He has authored or co-authored several research papers and book chapters, and also a digital textbook based on the usage of a Computer Algebra System for teaching analytic geometry. Most of his research is devoted to Mathematics and Mathematics Education in a technology-rich environment. He is an active member of national and international professional committees, editorial boards of research journals devoted to Mathematics Education and to technology in Mathematics Education.

Sara Hershkovitz retired from The Center for Educational Technology (CET) In Israel, after 4 decades. For 27 years (till 2017) she was head of the Mathematics Department and led the development of dozens of CET's Math textbooks for primary and secondary schools, as well as the interactive digital content and digital textbooks, and the development of the online course in Math for high school, which is a part of CET's Virtual High School (VHS). During 2017 to 2020 Prof. Hershkovitz was the head of the assessment and Evaluation Department, which was responsible for national and international exams in Israel and the research led by CET. She published books and research papers in the field of Problem Solving and Mathematics Education.

Zsolt Lavicza has worked on several research projects examining technology and mathematics teaching in classroom environments in Michigan and Cambridge. In addition, Dr. Lavicza has greatly contributed to the
development of the GeoGebra community and participated in developing research projects on GeoGebra and related technologies worldwide. Currently, he is a Professor in STEM Education Research Methods at Johannes Kepler University's Linz School of Education in Austria. From JKU he is working on numerous research projects worldwide related to technology integration into schools; leading the doctoral programme in STEM Education; teaching educational research methods worldwide; and coordinates research projects within the International GeoGebra Institute.

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The Frontline of Workforce Development: PreK-12 Education

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Jamie is a 17 year-old junior at a Midwestern high school serving an average size community anchored by a regional public university and an agricultural equipment manufacturer. Since middle school he did just enough to keep his grades from attracting remedial attention while falling short of competing for scholarships or elite colleges. With a 2.0 grade point average Jamie was adrift, preferring skate boards and video games to algebra and anatomy lessons. Like so many young Americans, he was lost at "C." A new course sequence that matched students and their teachers with local industry professionals in hybrid work-based learning experiences caught his attention, and Jamie started each day of the fall semester on a plant floor alongside engineers designing high pressure pumps for crop irrigation. It turned out that his formidable skills with Minecra translated to their computer-aided design platform, and his carves and airwalks on the skateboard imbued Jamie with an intuitive grasp of fluid dynamics—velocity, density, viscosity, pressure, temperature and the like. His grades have spiked and the pump company offered to scholarship his higher education in exchange for continued internships toward employment upon degree. Jamie's found his rudder. The Mission Statement of Jamie's school district is "To prepare caring and responsible citizens." Some suggest adding "employable."

For over a century, job-related career education was restricted to the CTE (Career and Technical Education) wing of US schools. Despite funding and credentialing hurdles, core discipline teachers from early elementary to secondary schools are adopting work-based strategies to add meaning and context to study. A third grade class in Jamie's district opened a neighborhood coffee shop in partnership with a local vendor, learning the botany of beans, the math of price-pointing, and the business of marketing all the while. The Chemistry class partnered with a local brewery to perfect a root beer recipe as their fermentation unit, earning royalties along with course credits. Such pockets of excellence inspired and informed the development of a new Federal STEM education five- year strategic plan released in late 2018.

Charting a Course for the Future: America's Strategy for STEM Education (https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf) is anchored to over-arching goals toward STEM literacy, diversity and inclusion, and preparing tomorrow's workforce. Thousands of voices throughout the public and private sectors, from employers to educators across State and Federal stakeholder groups were unanimous in advancing a workforce development goal: "A diverse talent pool of Americans with strong STEM knowledge and skills prepared for the jobs of the future is essential to maintaining the national innovation base that supports key sectors of the economy, including agriculture, energy, healthcare, information and communications technologies, manufacturing, transportation, and defense, along with emerging areas like artificial intelligence and quantum information science"(p. 6).

Among the dozen strategic priorities that constitute America's Strategy for STEM are four specific to more purposeful ties between the worlds of work and of education. They derive from the consensus of the STEM education community as recounted on page 44. Each is an invitation for PreK-12 educators to take frontline leadership in developing tomorrow's workforce:

1. Build Local STEM Ecosystems that unite schools, workplaces, informal learning centers, social service and faith-based entities and others in wrap- around support for learners across the pipeline, classroom to career (p. 10).
2. Expand Work-Based Learning for both students and their teachers through Educator-Employer Partnerships (p. 11).
3. Develop Entrepreneurship Education to drive innovation, invention, and discovery (p. 16).
4. Elevate Computational Literacy across disciplines as equal to reading and mathematics as foundations to career readiness (p. 23).

The elegance of a teaching-toward-workforce-development mindset is the alignment to learning theory—the content and skills conveyed can't help but be more personal relevant, meaningful, applied and culturally contextual. The authors of the Plan surmised, "Tomorrow's workers are today's learners, and the learning experiences provided to them will directly impact how many decide to pursue STEM careers as well as how ready they will be to do so" (p. 6). They recognize, however, that systems need to evolve alongside individual teachers for the vision to spread. Re-imagined policy around the credentialing of instructors and crediting of courses is needed at the local and state levels. Higher education admission expectations, teacher preparation models and research agendas all risk misalignment with the new priorities of the STEM education community. School administrators have the awesome responsibility and unprecedented opportunity, likely reinforced by tablemates at Rotary Club or city leaders' meetings, to usher a new era of STEM education woven into the community. Grant agencies and philanthropic organizations now have a "North Star" with which to chart their own courses for investing, thereby amplifying their collective impact.

It's a laudable mission statement for a school district "To prepare caring and responsible citizens." But "To prepare caring, responsible, and employable citizens" sets learners and their communities as well as our nation up for economic success.

Any opinions, findings, and conclusions or recommendations expressed are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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