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To cite this article:

Furner, J.M. (2024). Creating connections: Using problem-based instruction with mathematics and technology like GeoGebra for STEM integration. *International Journal of Education in Mathematics, Science, and Technology (IJEMST), 12*(4), 957-970. https://doi.org/10.46328/ijemst.4018

International Journal of Education in Mathematics, Science and Technology

2024, Vol. 12, No. 4, 957-970 https://doi.org/10.46328/ijemst.4018

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Article Info

Article History

Received:
08 November 2023
Accepted:
18 May 2024

Keywords

STEM
Technology
Problem-solving
Mathematics
GeoGebra
Video/Simulations
Science

Abstract

This paper will provide several examples of science and mathematics integration: navigation/map-reading, ecology/ecosystems/population growth, and chemistry/molecular structures. This paper underscores integrating STEM subjects with problem-based learning with technology such as video/computer simulations/programming/coding and the dynamic free online software GeoGebra. The paper suggests some GeoGebra-based connections to the science and math that is taught and a way to connect the disciplines with technology. Science involves and uses mathematics, and both subjects involve problem solving, and math is the tool that science uses. Subsequently, integrating science and mathematics using problem-based learning with technology might be a way to improve science and mathematics instruction while building confidence for STEM. Recommendations for STEM teachers are made along with some GeoGebra illustrations.

Introduction

STEM is not a class you teach. It's a culture you build.
– Chris Woods

Wonder is the beginning of wisdom.
– Socrates

GeoGebra can inspire technology integration in mathematics.
– Markus Hohenwarter

STEM is a worldwide buzzword in education and society today. There is great emphasis around the world related to science, technology, engineering, and mathematics as our world becomes more competitive and technological. In a test-driven curriculum where students and teachers are evaluated on student performance based on reading and mathematics standardized test scores, teaching meaningful science and mathematics remains a continued challenge. Research indicates that education major methods courses profoundly impact how a teacher will teach

(Haigh, 1985) it is critical to introduce preservice teachers to a contextual way of understanding the curriculum when learning how to teach science and mathematics (Furner & Kumar, 2007; Frykholm & Glasson, 2005). According to the Report of the 2018 National Survey of Science and Mathematics Education + (Banilower et. al 2018), the condition of science and mathematics in pre-college education are challenged today, math programs described that integrated instruction benefits students to grasp connections among science and other subjects on a regular basis when employed, unfortunately many elementary teachers do not feel prepared to teach science, and almost half feel confident in teaching math, confidence improves with middle school teachers for math and science and even more so at the high school level although math and science integration are not always commonplace in schools today unfortunately. Margot and Kettler (2019) found that teachers need time for collaboration and professional development to plan and do more integration of STEM into instruction.

There are many demands for integrating STEM in schools today made by educational organizations such as the School Science and Mathematics Association (SSMA), the American Association for the Advancement of Science (AAAS), the National Council of Teachers of Mathematics, and the National Research Council. Their strong support for the integration of math and science is reflected in documents such as the *National Science Education Standards* (NRC, 1996) and the NCTM *Standards* (NCTM 1989 and 2000). The National Council of Teachers of Mathematics (2000) makes "Connections" as one of their process standards and advocates the use of integrating subjects like mathematics and the sciences when teaching. A meta-analysis on STEM integration from Siregar et. al (2019) found the results in their conclusion of their meta-analytic study as "promising and provide an overall effect for STEM programs on students' mathematics achievement as positive and statistically significant" (p. 9).

Ramadhani and Narpila (2018) advocate problem-based learning using GeoGebra when teaching mathematics. GeoGebra serves as an important technological tool for doing the math and also modeling and using the data tables. It offers a great deal of dynamic simulations and modeling for the problem-based activities. Suweken (2020) also contends that GeoGebra offers a way to do problem-based learning when you use the technology as a tool to do the mathematics and model the problems. Selvy et. al (2020) also shows in their research that GeoGebra helps in improving students' mathematical creative thinking and motivation through GeoGebra assisted problem-based learning activities. Furner (2021a) also talks about the importance of building confidence in STEM fields like mathematics and using GeoGebra and other video/simulation/gaming approaches to teaching math to reach all students for a STEM world.

A Justification for Math and Science Integration

Research points to using an interdisciplinary or combined curriculum which offers chances for more pertinent, less disjointed, and more motivating practices for learners (Frykholm & Glasson, 2005; Koirala & Bowman, 2003). Integration of science and mathematics often leads to motivation (Friend, 1985; Wolfe, 1990) and an increase in student achievement in both disciplines (McBride & Silverman, 1991). Often students are unable to solve problems because they do not understand the context in which the problems are embedded (Frykholm & Glasson, 2005). The separate and often isolated subject curriculum can be viewed as a jigsaw puzzle without any picture for our learners. Amalgamation of mathematics and science can fetch organized lapping of ideas and ideologies in an expressive way to augment the learning framework for students. Today teachers can carefully design interactive videos/simulations which are suitable for creating real-life contexts for problem-based learning in mathematics integrated with science (Furner & Kumar, 2007).

Inganah et. al (2023) along with Berlin and Kyungpook (2005) argue in favor of integration in science and mathematics teacher education courses in order to facilitate a successful implementation at the K-12 classrooms. In a three-year study Koirala and Bowman (2003) found that preservice teachers' understanding of integration was enhanced in a middle school integrated math and science methods course, and they appreciated the emphasis on integration. Pyke and Lynch (2005) in a study of science and mathematics teachers preparing for the National Board for Professional Teaching Standards (NBPTS) certification and enrolled in an integrated prep course noticed higher scores and higher passing rates. In a study by Utley et. al (2005) they found a significant increase in the level of science and math teaching efficacy with integration.

Whereas there are ongoing reform efforts in integrating science and mathematics education, computer and interactive technology applications are making inroads into classrooms. For example, using GeoGebra software while teaching mathematics is an excellent way to model and engage students in learning mathematics (Furner, 2021b). In a high-tech globally competitive age, where knowledge of mathematics, science, and technology are critical, teachers must employ effective instructional strategies integrating mathematics and science. The study by Ziatdinov and Valles (2022) shows the effectiveness of GeoGebra and its programming key features in science and engineering, particularly in topics related to mathematics. Many key features of GeoGebra are thoroughly analyzed, along with how GeoGebra can be supportive in diverse topics are discussed in aiding in problem-based learning in STEM. Samura (2023) found that by using GeoGebra and problem-based learning that leads to improved mathematics critical thinking skills of middle-aged school students using a blended learning model with GeoGebra assisted mathematics learning activities. Muchlis et. al (2023) found that by teaching using problem-based learning with GeoGebra it aided in student engagement during the learning process which is critical today during instruction. Students need to see relevance to their learning and use tools that aid in the learning while making STEM connections. GeoGebra.org offers many teacher-made resources to use during instruction, many that relate to problem-based learning, the resources may be found at: https://www.geogebra.org/materials. Some GeoGebra images as resources will be shared in the figures below as they relate to each topic/problem-based activity (See Figures 1-3).

Videos, simulations, dynamic software, programming/coding, and gaming are all ideal tools for developing information rich contexts for anchoring problem-based learning in a context often deliberately enriched with data in the form of stories and episodes essential for active participation of learners for placing problem-based anchors with stories and episodes for teaching and using skills (Cognition and Technology Group at Vanderbilt, 1990). Computers, software, videos, gaming, and simulations all can play an important role in programming-based/coding/dynamic construction and problem solving. One of the aims of problem-based learning is to prepare students for life through the development of cognitive skills to solve real life problems presented in context. Students are able to engage in learning activities that they are able to relate to as meaningful and related to authentic context. This paper provides particular examples of problem-based learning with technology like

GeoGebra to integrate science and mathematics while employing the emerging technology.

GeoGebra Overview

GeoGebra was developed by Markus Hohenwarter in 2001/2002 as part of his master's thesis in math education and computer science at the University of Salzburg in Austria. GeoGebra software is a dynamic exploration and construction tool on a coordinate grid that enables students to explore and understand mathematics in ways that are not possible with traditional tools. GeoGebra software allows students to construct an object and then explore its mathematical properties by dragging the object using the computer mouse. *Cabri Geometry II* by Texas Instruments is also another popular sketching software. Most geometry sketching software brings dynamic power to the study of Euclidean and non-Euclidean geometries, algebra, trigonometry, precalculus, and calculus. This type of software can be adapted for use with young learners through college age and lends itself for much exploration and creativity.

Romero Albaladejo and García López (2023) found that mathematical attitudes can positively be transformed when introducing GeoGebra to mathematics instruction. They found new forms of behavior emerged as students used the software to gain confidence, checking and verifying their work, and feeling more confident as they used GeoGebra to do math to address affect in learning mathematics which is critical in gaining STEM confidence.

GeoGebra has been a growing favorite today among math teachers because it is free software, a multi-platform dynamic mathematics software for all levels of education that joins geometry, algebra, tables, graphing, statistics and calculus in one easy-to-use package (Hohenwarter et. al, 2009). Tytler et. al (2023) share a framework for integrating STEM and share how critical it is to address the challenges and benefits for promoting engagement in learning mathematics using tools like GeoGebra to motivate and allow for creativity and motivation in learning mathematics. GeoGebra has a large international user and developer community with users from 190 countries. The software is currently translated into 55 languages and attracts close to 300,000 downloads per month. It can be downloaded for free and accessed at: http://www.geogebra.org/cms/en/info.

Examples of STEM Integration

Interactive Video Simulations for Navigation and Map Reading

The innovative series of collaborative videos "*The Voyage of the Mimi*" was custom produced for affixing problem-based math and science learning for students to make connections to the math and science they are learning to life (The Voyage of the Mimi, 1984). The series includes many math and science concepts covered using a theme of the ocean on the hunt for Humpback whales with much adventure and math and science usage and connections. Created by Bank Street College of Education and Written by Richard Hendrick, this has been very popular in science and math classes and was a popular television series on *Public Broadcasting Service* (PBS).

The video series offer multiple opportunities for problem solving, reasoning, communication and making connections to other areas such as science, mathematics, social studies, literature, and history. Many schools use this series to teach about navigation, map reading, ecosystems, ecology, and oceanography. Many connections are made for math and science. In the videos students can explore about navigation as they go on the Mimi adventure (Wikipedia, 2023). Teachers can take their students on a learning journey or sorts, a navigation of sorts on the high seas with this production which includes 13 episodes in the original series.

Maps and Navigation is part of the software components of the *Voyage of the Mimi* series. Students learn navigation and mapping skills as they use some of the tools of a navigator which are a part of the software and kit of the program. Learners can imagine themselves escaping the path of a hurricane or searching for someone lost at sea. Student pages are designed to supplement the software are included with the kit for teachers. In addition, there are mathematical skills with a strong connection to science, including map reading, distance, ratios, proportion, and the measurement of length, area, and time to name a few. Students may use GeoGebra initially to learn about plotting points, distance, and coordinate planes as it then connects to reading maps (see Figure 1).

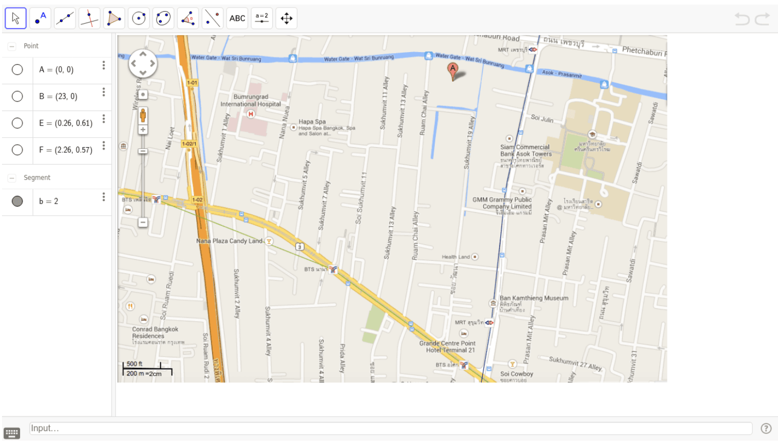

Figure 1. Calculating Real Distances from a Scaled Map in GeoGebra
Found at: https://www.geogebra.org/m/AUSFM2Md

The *Geography Field Work* Website by the Barcelona Field Studies Centre offers a great test and survey for reading maps and navigating, students can start by taking this test to show their understanding at: https://geographyfieldwork.com/Ben-Nevis-Map-Reading-Test.htm

Another website, *My Land Matters* is a wonderful resource for Map Reading & Navigation Tutorials & Guides, teaching about codes and symbols one needs to know when navigating and reading maps at: http://www.mylandmatters.org/Tutorials/MapReading/

Ziatdinov and Valles (2022) provide many examples and discuss with examples and modeling, visualization, and programming in GeoGebra and how it is an effective approach for teaching and learning STEM related to navigation and map reading. Furner and Ramirez (1999) share geographic information system (GIS) activities connecting math and science. Today most of this has now lead to GPS systems that most people carry with them in their cellular phones. Herceg and Herceg-Mandic (2013) provide examples of how GeoGebra can be used in

Geography class as well so to teach and give examples to navigation and maps. GeoGebra is an extremely useful tool especially in how it is designed and when you turn on the grid, the Cartesian coordinates are a great example of how a map works, assisting greatly in navigation. STEAM currently offers many gaming options for students, one *Virtual-O* is a great one to help with navigation and map reading and related to this theme, information can be found at: https://store.steampowered.com/

Ecology/Ecosystems Simulations and Population Growth with GeoGebra

The *Voyage of the Mimi* and the *Second Voyage* are great series to use to simulate the challenge of survival, our ecosystem, ecology, and population growth. Learners discover themes like energy, food networks, and inhabitants. Relationships among nine land species and nine pond species are explored with this series. Learners have to select four land species and four pond species and try to survive for one year without upsetting the ecosystem they have formed. Students can explore much about population growth as they use the series and its videos and simulations for ecology, ecosystems, and population growth. The two series offer many ways to teach about ecology, oceanography, ecosystems, and even population growth. Please see the examples included below and Figure 2.

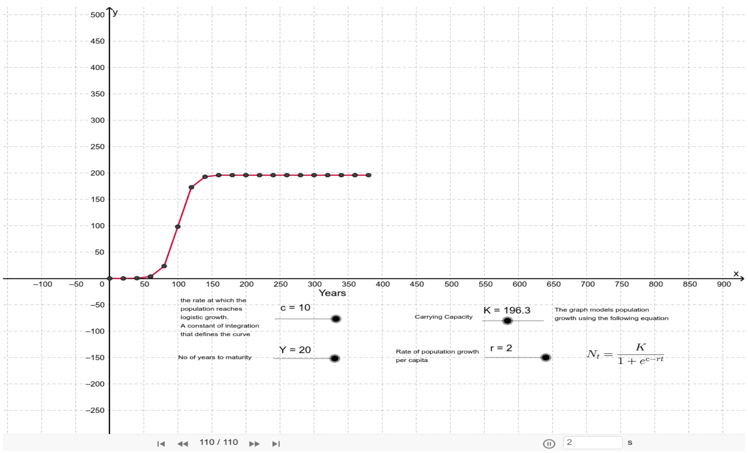

Figure 2. Modelling Population Growth with GeoGebra
Found at: https://www.geogebra.org/m/wBFc2yK9

A *Field Trip into the Sea* is software which introduces students to the diversity of life in the kelp forest and rocky shore habitat. It encompasses collaborative on-screen Field Guides for the learners, a data table of organisms, and activities dealing with food chain processes, that challenges pupils to identify predator/prey associations. *Explore and Discover* software is contained on the software simulations which allows students to explore in depth the many themes introduced in the Mimi adventures. *Whales and Their Environment* is a software and hardware component. It contains readings, activities, and experimentations using The Bank Street Laboratory, a computer-based laboratory, to study the physics of gravity, temperature, sound, and light. The resources for the laboratory also contains sensor probes, an interface, and the use of the computer to gather light, temperature, and sound data as part of the simulations and resources. Students can learn a lot about ecology, ecosystems, and even talk about population growth or loss of the Humpback whales.

The *Second Voyage of the Mimi* was completed in 1987 and offers many software components which further develop the math and science topics presented in the videos and gives students an opportunity to apply what was learned in simulated activities, such as: *A Field Trip to the Rainforest* where this software introduces students to the diversity of life in a Central American rainforest and ecosystem and ecology. It includes an interactive field guide with information about seventy plants and animals in the forest, and a food chain activity to help students identify predator/prey relationships in our ecosystem and ecology while looking at population growth of species and its impact on the ecosystem. *Maya Math* is another video showing students about the base twenty maya number system. The Maya Calculator, students can explore the Mayan people, their number system, and compare to other number systems. The Maya Calendar field trip students learn about how place value played a part in the Maya Calendar system. In the one called *Glyph Trek* learners apply their understanding of the Maya number scheme to discover an ancient Maya city. Explore and Discover software is contained on the video simulations which allows students to explore in depth the many themes introduced in the Mimi adventures. *A Field Trip into the Sky* is software which allows students to experience the mysteries of space. *The Sun and Moon Labs* are interactive laboratories in which students explore the sun-earth-moon relationships. The Field Guide includes out of this world photography, NASA videos and animation. A hypermedia databank, a visual catalogue, and some challenging educational games are included as part of the learning experience. *Scuba Science* another in the series shows the *Whales and Their Environment* component, *Scuba Science* uses the Bank Street Laboratory. It includes readings, activities and experiments using the micro-computer-based lab to study the physics of pressure, temperature, sound and light. The Bank Street Laboratory resources contain sensor probes, an interface box, and computer software to help gather light, temperature and sound data for students to collect.

There are many great websites and videos on simulations of ecosystems, one very useful one offers a deep dive into an ecosystem between fox and rabbits where students can understand about ecosystems found at: https://youtu.be/r_It_X7v-1E

The *Biology Simulations* Website is great to use to show simulations of different ecosystems related to: Biodiversity, Competition, Macroinvertebrates, Population Dynamics, and Soil Texture. Students can learn a lot about ecosystems and ecology with this website at: https://www.biologysimulations.com/ecology

The *BioInteractive* is a great website for students to be able to see population dynamics and allows students to explore two classic mathematical models that describe how populations change over time: the exponential and logistic growth models are shared and simulated at: https://www.biointeractive.org/classroom-resources/population-dynamics

The *Annenberg Learner* is one of the best websites for teaching about ecology and ecosystems at covers a wide range of topics related to The Habitable Planet: A Systems Approach to Environmental Science. They have many units, videos, and interactives to explore with to learn about our environment, ecosystems, and ecology at:
https://www.learner.org/series/the-habitable-planet-a-systems-approach-to-environmental-science/ecology-lab/

Abrahamson and Abdu (2021) designed an ecological-dynamics design framework for embodied-interaction conceptual learning and address ecology while using GeoGebra showing such a case of dynamic with such software. Biró and Geda (2014) offers some GeoGebra simulation possibilities through phenomena of various disciplines like ecology. Cioruţa et. al (2012) show how GeoGebra software show new possibilities for studying the environmental problems we have in our world; this was published in *The Journal of Environmental Research and Protection (Ecoterra®)*. GeoGebra offers many uses and connections to many STEM areas and can serve as a tool to assist in scientific modeling with ecology like in Figure 2. *Labster* offers simulations online with control of populations and Ecology where students can explore many sciences aspects while also doing math with data collection and Ecology at: https://www.labster.com/simulations/population-growth.

Mathematics and Molecular Structure Connections/Simulations

There are powerful connections between chemistry and mathematics, and it is useful to bring these concepts into the classroom using computer technology like GeoGebra and computer simulations. Some case studies of individual students through some research below is shared showing how these activities can be extended to the classroom and making connections for math and science, like chemistry, with examples of integrating science and mathematics from the perspective of the classroom teacher.

In chemistry the methane molecule, composed of a central carbon atom surrounded by four equally spaced hydrogen atoms, lends itself to a mathematically rich exploration. This molecule can be modeled using an open tetrahedral form (similar to the ones made in class out of toothpicks and foam balls as described below from the website) and a glycerin solution. Students can then see the six planes of the molecule and the angles formed by the line segments from the center sphere to each vertex can be measured. See the GeoGebra Model of the Methane Molecule in Figure 3. The University of Colorado at Boulder offers a Simulation to build molecules, atoms, balancing chemical equations, look at molecule polarity, etc. with their PHET Interactive Simulations software at at: https://phet.colorado.edu/en/simulations/build-a-molecule. This is a great resource to use to model and simulate molecular structures.

Research by Ploger and Lay (1992) show in their case study and examine how a student (Stan) wrote computer programs to draw molecules. Stan wrote a procedure to draw the structure of glucose, a molecule with 24 atoms. His program had forty-two commands. Essentially, his program would draw an atom; then move to the next place. Although the teacher realized that the program needed to be organized, the student did not want to change a program that worked. At that point, the teacher showed the structure for galactose, a molecule very similar to glucose. Stan realized that it would be reasonable for him to modify his program to draw this similar molecule. Allowing students to explore with computer programming gives students opportunities to refine their skills to coding. With the tools, the program had a clear structure that corresponded to the structure of the molecule (See Figure 3 with the GeoGebra model). From this case study the student realized that glucose was a specific kind of molecule. In this way, the difference in the structure of the procedures reflected the difference in the structure of the molecules. After the student applied the power of sub procedures, the Molecular Toolkit could draw more than 200 molecules. The program was then extended so that it could show the decision-making processes used to name a molecule (Ploger, 2004). At every stage of the work, the connections between mathematics and molecular structure were made clear. In addition to exploring the complexity of the connections between mathematics and chemistry, it is also useful to examine relatively simple mathematics problems and connect them to the science.

Students can learn about the Methane Molecule with some great videos, like:

https://youtu.be/uiYO32j_eP8

Generation Genius also has a wonderful video for learners to use to learn about methane molecules at:

https://www.generationgenius.com/videolessons/atoms-and-molecules-video-for-kids/

There is also a great website that can really help students understand molecules at:

https://www.worldofmolecules.com/fuels/methane.htm

The *ACS Chemistry for Life* website is a great resource for allow students to manipulate by clicking on the 3-D model and seeing it from various angles allowing for representational models of the molecule at:

https://www.acs.org/education/resources/undergraduate/chemistryincontext/interactives/climate-change/3d-model-of-methane.html

The following website offers a way to create a hands-on concrete model of the molecule at:

https://www.ehow.com/how_8307913_make-model-methane-molecule.html

Using the following: 5 foam balls, 1-inch wide, Acrylic paint, Paintbrush, Toothpicks

They give step-by-step directions and models for making a concrete hands-on model of the methane molecule.

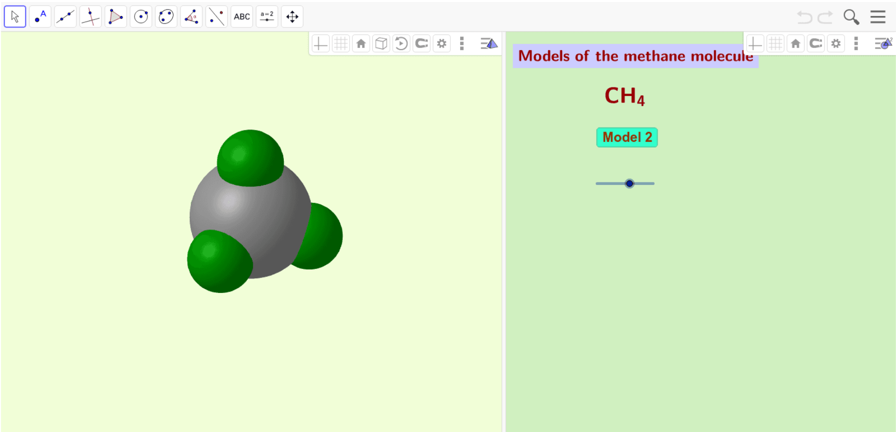

Figure 3. Models of the Methane Molecule with GeoGebra Software
Found at: https://www.geogebra.org/m/NtrFAK3w

The objective of these activities is to offer students concrete hands-on experiences to help visualize abstract geometric ideas. The activities are consistent with van Heile's model of learning mathematics. In addition to this, the activities address an important standard--connecting geometry to other areas of math and science and learners can use technology like GeoGebra to model such concepts. Today, GeoGebra plays a critical role in mathematics instruction and assists the learning in advancing the subject greatly as a tool in the pursuit of doing mathematics (Furner, 2021b). Falcón and Ríos (2015) found that GeoGebra is very useful in creating and modeling molecular structures, emphasizing the importance of the technology while teaching such concepts. Such models and experiments were modeled using GeoGebra and shared in Nurmakhanov (2021).

Recommendations for STEM Teachers

So, where should the integration of science and mathematics begin? Since research indicates that methods courses profoundly impact how a teacher will teach it is critical to introduce preservice teachers to a contextual way of understanding the curriculum when learning how to teach science and mathematics. As a general principle Beane (1992) suggested, first, identifying a central theme and second, asking the question what each subject area can contribute to the theme. More specific recommendations are outlined in (Furner, 2023; Furner & Ramirez, 1999; Sunal & Furner, 1995), below are a summary of suggested recommendations for STEM educators for integration:

-Collect and apply data in problem-based integrated activities that invoke process skills. For example, as discussed earlier, implement technologies to generate a context for math and science integration based on data. Use GeoGebra to model or create data tables where students are using the math and technology as they are doing the science.

-When teaching the math/science concepts try to teach them using hands-on/concrete models, then connect to representational models with pictures/diagram/videos/simulations, lastly then allow students to use software like GeoGebra to make the abstract connections using the technology to reinforce their deeper understanding of the concepts this is consistent with the Piaget approach to learning.

-Use instructional strategies suitable for closing the gap between students' classroom experiences and real-life experiences outside the classroom where they see connections between the two subjects. Allow students to see how math is the tool scientist use to do science.

-Introduce the integration of science and mathematics, problem-based learning and related technology applications in teacher preparation programs so teachers are trained and are using this approach with young learners so to strengthen STEM.

-Provide professional development opportunities for practicing classroom teachers in the integration of science and mathematics with problem-based learning with technology. Giving examples like above to show such integration and connections.

- Using dynamic software like GeoGebra which is free for the learners with so many teacher resources now where students can model and/or create data tables where learners are using the math and technology as they are doing the science. Technology is emphasized so much today in learning and needs to be incorporated.

-Use interactive simulations and videos/gaming as a part of simulating/modeling and promoting problem-based learning during instruction that can connect the mathematics and science that is used.

-Integration is critical in mathematics and the sciences as we want to build better connections and also build confidence in students in these disciplines so that more young people will pursue such STEM fields going forward.

Closing Thoughts

There is optimism for integrating science and mathematics through problem-based learning with technology. Such connections are very meaningful to learners. GeoGebra is one example used here to show how it can fit into classroom instruction. Problem-based learning is an area where successful integration of science and mathematics could be achieved as described above. Integrating science and mathematics helps to motivate and engage students in meaningful learning experiences. It is highly recommended that both teachers in preparation as well as practice be provided with the skills and knowledge to integrate science and mathematics to make such connections. Teaching integrated science and mathematics in K-12 will not only benefit students academically but also develop in them the skills essential to survive in a science and technology dominated society. STEM integration has been around for many decades prior to the term STEM even coming to the forefront of society, integration and interdisciplinary instruction is critical in making relevant connections for learners which can help foster STEM interest and confidence as well. Instilling wonder in learning and making such math and science connections are critical for STEM advancement. Building a culture of STEM and using the emerging technologies are effective means for preparing our young people.

In a world which has become so heavily driven by technology, mathematics, and science it is critical we emphasize and elevate student achievement in these STEM areas. Today STEM educators should take a more proactive part in reassuring teachers and students to become enthusiastic about mathematics and seeing themselves as successful, confident mathematical problem solvers in a technological era requiring much knowledge related to mathematics, the sciences, the use of technology, and problem solving as now and in the future as our young people will be competing with others from around the globe for high-tech jobs in this now STEM world, we live in.

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