Innovation Spotlights:

Nine Dimensions for Supporting Powerful STEM Learning with Technology

DEPARTMENT OF EDUCATION • UNITED STATES OF AMERICA

OFFICE OF
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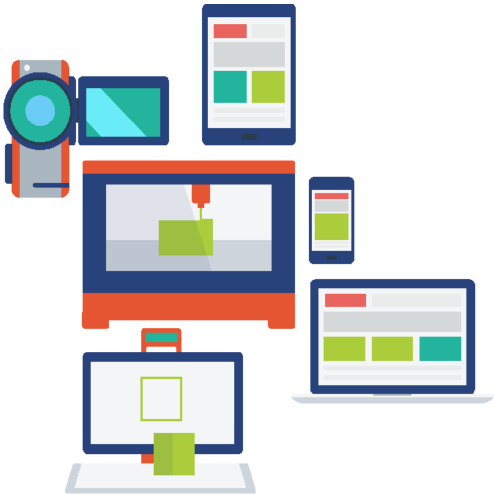
Introduction



We live in a time of staggering technological change, with disruptive technology innovations continually reshaping how we live and work. One example is the indispensable role technology now plays in science, technology, engineering, and mathematics (STEM) professions. To prepare young people for citizenship and a workforce with rapidly changing requirements, we must design learning environments that provide all students with unique and engaging opportunities to master STEM skills using the technologies STEM professionals use.

This is already occurring in our nation's schools. Coding courses and workshops engage students in computational thinking. 3D modeling software and printers let students become "makers" solving real-world problems through design and engineering. Robotics competitions combine digital coding and design with physical building to help students learn collaboration and problem-solving skills. With augmented reality, students can now develop field research skills while exploring simulations of ecosystems in faraway places.

Still, as with all educational innovations, bringing technology into classrooms alone does not ensure better outcomes. Powerful learning experiences also require effective teachers who make instructional decisions based on evidence of enhanced student learning.

To help teachers implement new, research-based approaches for leveraging technology to improve STEM learning, the U.S. Department of Education, in collaboration with Digital Promise, conducted a systematic review of the research literature on the impact of integrating innovative digital technology in STEM and computer science curricula and classrooms. For purposes of the review, we defined digital technology broadly to include various forms of computing devices and software applications, including sensors connected to computing devices, digital immersive environments, cellular devices and mobile applications, as well as collaborative technologies.

The research review identified nine dimensions of effective STEM learning practices enabled by technology, which are described in this report. The report also provides links to videos developed by the Department and Digital Promise that highlight the research-based dimensions in action in 10 spotlight schools (Exhibit 1). The purpose of the STEM spotlights is not to advocate for technology for its own sake, but rather to illustrate meaningful, research-based STEM learning experiences that can be supported with digital tools in classrooms across the country.

An appendix provides additional detail on the methodology used for the research review.

Nine dimensions of powerful STEM learning

The review of the literature surfaced nine dimensions of powerful STEM learning that can be supported with digital technology. The review looked at studies of supports for students' development of STEM and computational thinking knowledge and practices (skills) that provided evidence of student learning outcomes, as measured by an objective test and not just self-reported perceptions of learning. The nine dimensions were checked for consistency with conceptual framings and empirical findings from the Department of Education's Policy and Program Studies Service and the Institute for Education Sciences, as well as key policy documents such as the National Science & Technology Council's 2018 report, *Charting a Course for Success: America's Strategy for STEM Education*[1]. Our process also involved soliciting input from STEM education research experts. Below we present top-line summaries of the nine dimensions.

1. **Dynamic Representations.** Students learn or master STEM concepts through interacting with digital models, simulations, and dynamic representations of mathematical, scientific, and engineering systems.
2. **Collaborative Reasoning.** Technology tools support students' collaborative reasoning around STEM concepts, equalizing participation among group members and helping individuals and groups improve their ideas.
3. **Immediate and Individualized Feedback.** Digital tools provide students practicing or learning STEM skills or concepts with immediate and individualized feedback beyond right or wrong.
4. **Science Argumentation Skills.** Students use technology that supports science argumentation skills including presenting and evaluating evidence about scientific or mathematical claims.

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[1] White House of Science and Technology Policy (2018, December)

5 **Engineering Design Processes.** Students plan, revise, implement, and test problem solutions using engineering design processes and appropriate technologies.

6 **Computational Thinking.** Students use technology to problem-solve using algorithms, data, and simulations to investigate questions and develop new understandings about phenomena.

7 **Project-based Interdisciplinary Learning.** Students use digital technology tools in the context of project- or challenge-based learning activities that integrate multiple STEM fields (e.g., science and mathematics).

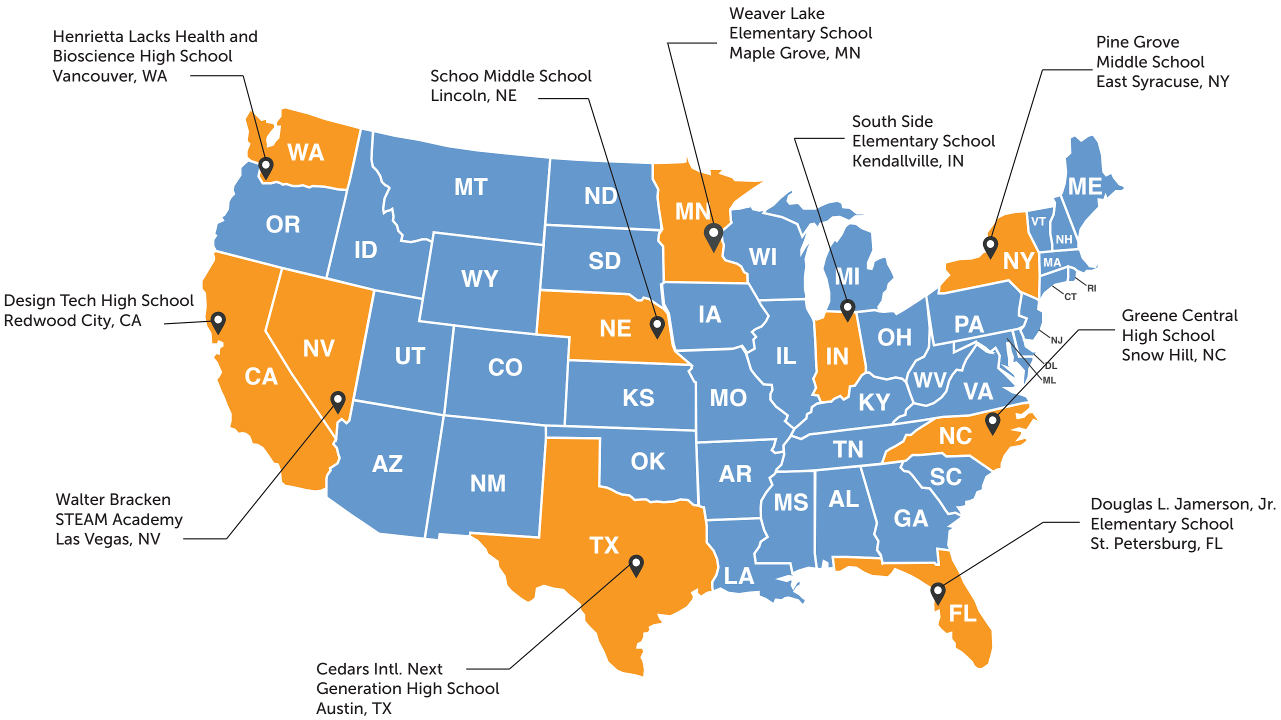
8 **Embedded Assessments.** Digital assessments are embedded in STEM instruction to prompt students' reflection on the quality of their explanations, models, or problem solutions.

9 **Evidence-based Models.** Students use technology to develop models based on data and evidence.

The nine dimensions served as a framework to identify 10 schools that could be spotlighted for implementing one or more of the STEM dimensions in their classrooms. Spotlight schools were selected based on nominations from a Technical Working Group of leading education researchers and other individuals knowledgeable about technology use for powerful STEM learning. Also considered were schools recognized as models of STEM education such as Future of Education Technology's STEM Excellence Award finalists and winners, Intel Schools of Distinction Award finalists and winners, and schools profiled in policy reports such as Monitoring Progress Toward Successful K-12 STEM Education (NRC, 2013).

This process identified 100 schools, each of which were invited to submit an application that asked them to describe in detail a classroom lesson that used technology for addressing one or more of the STEM dimensions. Of these, 34 schools submitted applications and 15 were interviewed about their suitability as a spotlight school. During the selection process we sought to include a broad representation of geographic areas and a range of grade levels (i.e., elementary, middle, and high schools). Exhibit 1, below, shows the names and locations of the final 10 spotlight schools.

Exhibit 1. Names and locations of the ten spotlight schools.



The following section provides more details about the nine dimensions and the 10 spotlight schools. Each dimension is supported with examples of powerful practice from the research literature and highlights an exemplary STEM lesson from one of the 10 spotlight schools.[2]

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[2] Information for school "Quick Facts" obtained from the *Institute of Education Sciences* National Center for Education Statistics website.

1. Dynamic Representations. Students learn or master STEM concepts through interacting with digital models, simulations, and dynamic representations of mathematical, scientific, and engineering systems.

Dynamic representations such as digital models, interactive simulations, and virtual environments are fundamental tools used by scientists, mathematicians, and engineers. Based on a computer model, dynamic representations engage learners and help them construct more accurate mental models of natural or engineered phenomena that would otherwise be difficult or impossible to observe.[3] Dynamic representations vary widely and differ in the levels of control and interactivity they provide to students. To better support learners, they are often augmented with pedagogical scaffolds that guide students when learning about STEM systems and processes. A study on middle school students' physics learning, for example, found that there was a significant reduction in students' misconceptions about motion and force after using a simulation-based learning environment that included such scaffolds.[4] In high school mathematics, the interactive software SimCalc has been shown to significantly improve how students learn core algebra concepts that include procedural and conceptual problems.[5] In a meta-analytic study on simulations, researchers found that students using simulations for STEM learning performed better on measures of learning than students engaged in equivalent activities that did not involve simulations.[6]

Walter Bracken STEAM Academy

At Walter Bracken a teacher uses an interactive simulation to teach third graders about weather and climate. Students use the online simulation to take temperature readings of two different places in the United States. Using the technology tool, students can go forward in time to see different measurements of temperature, humidity, rain, and wind direction. Students use tablets to graph the data to observe patterns and share their findings with one another. Since Las Vegas has limited weather variability, students are engaged and have fun when learning about weather in different parts of the country, an activity that would not have been possible without the use of digital technology.

Quick Facts

Location: Lincoln, NE (rural, fringe)

FRPL: 44%	Asian: 3%
Black 4%	White: 73%
Hispanic: 11%	Other: 9%

[Watch the Walter Bracken STEAM Academy video!]

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[3] National Research Council (2011)
[4] Huang et al. (2017)
[5] Hegedus et al. (2015)
[6] D'Angelo et al. (2014, March)

2. Collaborative Reasoning. Technology tools support students' collaborative reasoning around STEM concepts, equalizing participation among group members and helping individuals and groups improve their ideas.

Collaboration facilitates learning through students' ongoing efforts to construct and maintain a shared understanding of a problem.[7] When students work together to reason about STEM ideas, they engage in negotiation and renegotiation around meaning. Technology can enhance collaboration by expanding the kinds of exchanges students can have and by increasing access to community knowledge. Research has shown that students benefit more from collaborative activities when they receive support and guidance for interacting with one another.[8] In a study of fourth graders learning science, use of a digital collaboration platform that included e-sticky notes facilitated richer collaboration and resulted in stronger responses to open-ended questions. Observations showed that the technology also appeared to help equalize participation—students were more encouraged to change their minds and were less likely to dominate the conversation or to acquiesce to other students dominating classroom interactions when using the collaboration platform.[9] Fifth-graders who used Mindtool to create science concept maps that were shared and discussed with peers had higher achievement scores than students engaged in the same activity using hand-drawn maps.[10]

Philip H. Schoo Middle School

At Philip H. Schoo Middle School students learn how sound reaches far distances using a unit from the Next Generation Science Storylines. Students begin by observing the perplexing phenomenon of sound being generated when a pin is dragged over a vinyl record. This observation leads students to generate questions related to the causes of sound and how it reaches the ear. Students then create digital models using laptops to answer their initial questions, leading to the generation of even more questions. The Schoo teachers use a class consensus model for this unit, with students sharing their questions using an online communication and collaboration platform and on a driving question board. Students work in groups to answer questions and develop new ideas as they learn what their peers are thinking. The teacher projects every student's digital model in front of the class and together they discuss how the different representations are similar to or different from the scientific model. In this way, teachers are able to co-construct with their students the questions that drive scientific inquiry.

Quick Facts

Location: Lincoln, NE (rural, fringe)

FRPL: 44%
Asian: 3%
Black 4%
White: 73%
Hispanic: 11%
Other: 9%

Watch the Philip H. Schoo Middle School video!

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[7] Roschelle & Teasley (1995)
[8] Dillenbourg (1999)
[9] Lan et al. (2010)
[10] Hwang et al. (2011)

3. Immediate, Individualized Feedback. Digital tools provide students practicing or learning STEM skills or concepts with immediate and individualized feedback, beyond right or wrong.

Feedback is considered one of the most powerful means for influencing student learning.[11] When accompanied by challenging goals, feedback informs learners about the level of performance that is required so they can set reasonable goals and direct their actions and effort accordingly.[12] When learning goals are clear and students are committed, feedback can help students reduce the gap between their current level of performance and the intended level.[13, 14] Feedback can take a number of different forms depending on the learning goals of a lesson. For example, when students are engaged in tasks such as test-taking, some delay in feedback is beneficial. When students are engaged at the process level, however, as when processing classroom activities, immediate feedback is more desirable.[15] For example, a quasi-experimental study involving 4,000 second grade students from 129 classrooms found greater learning gains in basic calculation skills when students practiced their arithmetic skills using a computer and received immediate feedback about their response.[16] Feedback on task-based activities can be provided at both the individual and the group level. When provided at the group level, learners must decide if the feedback is relevant to them individually, to the group as a whole, or to other individuals.[17] A study of fifth-graders found that students learned fractions faster when the software provided individualized feedback about their misconceptions beyond whether their response was correct.[18]

Greene Central High School

Quick Facts

Location: Snow Hill, NC (rural, distant)
FRPL: 96% Asian: 0%
Black 43% White: 32%
Hispanic: 25% Other: 1%

At Greene Central High School in Snow Hill, North Carolina, students regularly receive individualized and immediate feedback while learning mathematics. Using tablets, students watch videos of their teacher working through a problem set and then work through the problems themselves. The technology enables the teacher to see what each student is doing, so s/he can spot students who are struggling with a particular kind of math problem. The teacher can provide just-in-time tailored supports for a struggling student in the form of hints or worked examples. The ability to access data about each student in real-time enables quick interventions that are individualized based on each student's needs. The technology also provides the teacher with dashboards showing data about each student as well as about the entire class so s/he can see where students need help and which math standards they are struggling with.

Watch the Greene Central High School video!

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[11] Hattie & Gan (2011)
[12] Locke & Latham (1990)
[13] Hattie & Timperley (2007)
[14] Kluger & DeNisi (1996)
[15] Kulik & Kulik (1988)
[16] Beserra et al. (2014)
[17] Nadler (1979)
[18] Chu et al. (2014)

4. Science Argumentation. Students use technology that supports science argumentation skills including presenting and evaluating evidence about scientific or mathematical claims.

Science argumentation is a thought process that requires critical thinking to present and defend evidence that explains an idea about scientific phenomenon.[19] Argumentation is central to the practice of all fields of science. In the classroom, science argumentation enables students to construct knowledge and empowers them to criticize plausible-sounding ideas that lack supporting evidence.[20,21] Technology can promote science argumentation in a number of ways. A 2011 study tested the impact of computer-based scaffolds for argumentation on middle school students' ability to evaluate evidence-based arguments during problem-based learning. Components of arguments that were tested included making claims, providing evidence that supports the claim, and explaining the relevancy of the evidence for supporting the argument in a claim. The researchers found a significant improvement among lower-achieving students' ability to evaluate the quality of scientific arguments after using the computer-based scaffolds. A different study of 960 middle school science students found that students improved their science argumentation skills through an online, multiplayer game that was instructionally designed to integrate scientific argumentation. Students who played the game 10 times or more improved in all aspects of argumentation, including understanding a claim, judging evidence about a claim, determining the reasoning applied to the claim, and making judgments.[22]

Weaver Lake STEM Elementary School

Quick Facts

Location: Maple Grove, MN (suburb, large)

FRPL: 35% Asian: 22%
Black 26% White: 42%
Hispanic: 4% Other: 7%

AAt Weaver Lake STEM Elementary School in Maple Grove, Minnesota, fourth graders engage in a year-long study about lake health to learn science argumentation skills using data and evidence. Guided by the question, "Is the lake healthy?" students pay monthly visits to a nearby freshwater lake to collect environmental data with digital tools used by real scientists. Students use probes to record water and soil temperatures; collect samples of lake water; and use a turbidity tube to record water clarity. Students also take digital photographs of the lakefront to document seasonal observations at different times of the year. Back in the classroom, students are tasked to create a website that lets the broader school community know whether or not the lake is healthy based on their data. Technology permits students to effectively display the evidence that they collected over the school year (including graphs and photos), articulate their arguments, and revise their arguments as needed. These data provide students with the opportunity and motivation to enhance and expand the efficacy of their scientific argument and presentation.

(continued)

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[19] Berland & Reiser (2009)
[20] Berland & Reiser (2010)
[21] Ford (2008)
[22] Ault et al. (2015)

Third graders at Weaver Lake engage in scientific argumentation as part of a year-long study of ornithology. In the Create-a-Bird project, students start by learning about Minnesota birds and the variety of beaks, feet, habitat, and diets that are associated with different bird species. Students then get to create their own species of a bird by creating and animating a digital model. Students then have to craft an argument about the appropriateness of their bird for a selected habitat. Students use facts about birds as evidence to explain their thinking about why the feet and beak of their bird are right for the habitat they choose.

Watch the Weaver Lake STEM Elementary School video!

5. **Engineering Design Processes**. Students plan, revise, implement, and test problem solutions using engineering design processes and appropriate support technologies.

Engineering can be defined as the process of designing for the human-made world.[23] Like science, engineering involves both iterative and systematic processes. Engineers test and modify each new version of a design based on available knowledge, and then systematically undertake steps to improve the design.19 Using data, engineers ask questions to understand the design problem, determine criteria for a successful solution, and identify constraints.[24] Digital tools play a central role in the engineering design process. In education, technology tools provide increased opportunities for students to apply scientific and mathematical ideas to their designs. Fan and Yu's (2017) quasi-experimental study of high school students found improvements in STEM domain knowledge and higher order thinking skills, including problem solving abilities and procedural knowledge, for students who completed four units of an engineering module that integrated components of science and mathematics. Students constructed a cam mechanism toy using lever scales, a gear-wheeled range finder, and a gear sets and then used computer aided design (CAD) software to simulate and analyze motion and the speed ratio of different gears. In middle school, seventh-graders knowledge gains in engineering and math were higher when they used technology tools for data analysis and measurement within a curricular unit on heat transfer.[25]

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[23] National Academy of Engineering (2008)

[24] Feder et al. (2009)

[25] Guzey et al. (2017)

Douglas L. Jamerson, Jr. Elementary School

Quick Facts

Location: St. Petersburg, FL (city, large)

FRPL: 53%	Asian: 3%
Black 37%	White: 48%
Hispanic: 7%	Other: 5%

At Jamerson Elementary in St. Petersburg, Florida, children learn the engineering design process of "Plan, Design, Check, and Share" starting in kindergarten. By third grade, students learn about insulators and conductors and apply their knowledge when planning and making insulators with the goal of keeping ice cubes from melting. A variety of technology tools support the students' engineering design and evaluation activities. Drawing on knowledge from previous lessons in earlier grades about insulators and conductors, students start by collaboratively planning their ice incubators by drawing out prototypes and talking through their ideas. During the design stage, students test the temperature of different materials, such as black and white paper and aluminum foil, to see which has the lowest temperature. After adding ice cubes to the insulators, the initial temperature is taken prior to leaving the insulators outside in the sun for 30 minutes. Students then check their design by using probeware to take multiple readings of the temperature, which are later graphed on a chart and used as data. Back in the classroom, students take out their ice vessels and measure the millimeters of liquid to see how much water had melted. As a class, students share out their design challenges to investigate which materials made the best insulators.

Watch the Douglas L. Jamerson, Jr. Elementary School video!

Design Tech High School

Quick Facts[26]

Location: Redwood City, CA (suburb, large)

FRPL: 11%	Asian: 20%
Black 0.4%	White: 50%
Hispanic: 13%	Other: 17%

At Design Tech High School in Redwood City, California, students use different digital tools and the engineering design process to propose, plan, scope, and budget a semester-long engineering project. In small groups, students create a personalized, resin table, in one case to reflect aspects of the local peninsula and the previous location of the school. Students create digital drawings of their table, using the size dimensions to calculate the amount of materials they need. They use a Gantt chart to plan out their work for each week of the project, with students making adjustments as needed, for example, when they find out some of their materials are unavailable. Students learn important skills throughout the entire design process, initially working as a team and then separating into individual roles. Students learn to use new tools to manage and implement a process in which mistakes and solving unanticipated problems are both important and necessary.

Watch the Design Tech High School video!

[26] Information for Design Tech High School "Quick Facts" obtained from the California Department of Education website.

6. Computational Thinking. Students use technology to problem-solve using algorithms, data, and simulations to investigate questions and develop new understandings about phenomena.

Computational thinking involves the formulation and analysis of problems and their solutions using methods and tools for reasoning abstractly and automating procedures through algorithmic thinking.[27,28] In education, the practices learned through computational thinking are widely applicable to topics in science and mathematics and provide a real-world and applied context for working with abstract datasets.[29] For example, a quasi-experimental study with high school students found that teaching computational thinking in conjunction with computer programming resulted in greater improvements in students' reasoning skills, including making conjectures and drawing conclusions from data.[30] In the study, students developed a computer program from source code based in algorithmic thinking and then used the program to solve a mathematics problem set. The code was transferred into MATLAB to generate graphical representations of the solution that illustrated the correctness of the code and the solution of the exercise. A study of rural and indigenous middle school students also showed learning gains from using robotics and game design that relied on abstraction skills, logical thinking, use of algorithms, and analyzing and implementing solutions.[31] Samples of student work were analyzed for evidence of computational thinking.

South Side Elementary School

At South Side Elementary School in Columbus, Indiana, STEM education includes computational thinking, which begins in kindergarten and continues through fifth grade. For example, in second grade, students engage in a coding activity to illustrate a butterfly's life cycle. Older students create robots or other machines, an activity that requires them to think computationally and procedurally as they solve problems in their design. By working through their coding errors, students come to understand that computational thinking involves ongoing trial-and-error and that persisting through mistakes or failures is an important part of the process. Teachers value coding activities for their connection to mathematics and the engineering design process, and for teaching students how to explain their reasoning and thinking to other people.

Quick Facts

Location: Kendallville, IN (town,distant)
FRPL: 64%
Asian: 0.2%
Black 0.5%
White: 84%
Hispanic: 12%
Other: 3%

Watch the South Side Elementary School video!

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[27] Basu et al. (2014)
[28] Grover & Pea (2013)
[29] Wing (2008)
[30] Psycharis & Kallia (2017)
[31] Leonard et al. (2016)

7. Project-based Interdisciplinary Learning. Students use digital technology tools in the context of authentic project- or challenge-based learning activities that integrate multiple STEM fields (e.g., science and mathematics).

Research shows that using an interdisciplinary curriculum that integrates multiple STEM subjects provides students with a more relevant, more engaging, and less fragmented learning experience.[32] In the context of project- or challenge-based learning, students can pursue solutions to real problems in the same way that professional scientists do.[33] In this context digital technologies can be used to find, organize, and communicate information and ideas; to support task management and productivity; and to create a final product. When teachers use this instructional approach, students' learning activities culminate in a tangible and sharable product that adequately addresses the problem or question.[34] The final product or artifact gives students an opportunity to publicly display their work and to practice presenting and explaining their project's outcomes to others. With project-based interdisciplinary activities, students not only learn important STEM content and practices, but also practice applying them in conjunction with other skills and knowledge in a realistic context.

Henrietta Lacks Health and Bioscience High School

Quick Facts

Location: Vancouver, WA (city, midsize)
FRPL: 41%
Asian: 9%
Black 2%
White: 66%
Hispanic: 15%
Other: 8%

Henrietta Lacks (HeLa) Health and Bioscience High School in Vancouver, Washington provides students with interdisciplinary project- or challenge-based learning through a project in which students learn about the chemicals in sunscreen and their impact on the environment. The challenge starts by creating a model of a molecule that's commonly found in over-the-counter products including sunscreen. Through their research, students learn that certain compounds such as oxybenzone are harmful for coral reefs and for your skin. In their investigations students use the authentic and freely available PubChem database of chemical information and 3D interactive chemical structure models. For their culminating artifact, students create a project poster as well as a public information piece in the form of a sunscreen brochure. Students present their research to the entire class and describe how the active ingredients found in sunscreen affects coral reef systems and human health.

Watch the Henrietta Lacks Health and Bioscience High School video!

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[32] Frykholm & Glasson (2005)
[33] Krajcik & Blumenfeld (2006)
[34] Blumenfeld et al. (1991)

8. Embedded Assessments. Digital assessments are embedded in STEM instruction to prompt students' reflection on the quality of their explanations, models, or problem solutions.

When embedded in STEM instruction, digital assessments can provide rich information about the nature and quality of students' STEM practices during scientific inquiry.[35, 36] When used for formative purposes, assessments provide a valuable opportunity for adapting instruction to better meet learners' needs.[37] Such assessments are especially powerful when they fuse core STEM ideas with STEM practices. A study by Zaidi (2016), for example, investigated the impact of embedded formative assessments designed to promote integrated science knowledge. The assessment allowed students to receive both peer and expert feedback on their knowledge products, which students then used to revise and resubmit their products. Study findings showed that the formative assessment improved science learning for all students but was particularly effective for students from underrepresented groups. Moreover, a qualitative analysis of students' knowledge artifacts revealed that students' peer reviews became increasingly elaborate and specific over time, enabling them to produce higher quality integrated knowledge products.

Pine Grove Middle School

Quick Facts

Location: East Syracuse, NY (rural, fringe)
FRPL: 45%
Asian: 2%
Black 4%
White: 87%
Hispanic: 2%
Other: 4%

At Pine Grove Middle School in Syracuse, New York, students complete embedded assessments during a science lesson about the impact of organisms on the ecosystem. The lesson starts with a check-in question about what would happen if certain species were removed from the food chain. The question sets the context of the lesson, which is driven by students' curiosities about food chain impacts. Students add their ideas to a collaborative document where they receive feedback from their peers. Facilitated by the technology, students reflect on and synthesize ideas which often results in the formation of new or revised understandings about the topic. In the second part of the lesson students focus on what would happen to the food chain if certain species were added. Students submit their answers online where the teacher can also provide real-time feedback to individual students. An important factor for the successful use of digital technology, a teacher notes, is to ask meaningful questions that do not require a yes/no response.

Watch the Pine Grove Middle School video!

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[35] Songer & Gotwals (2012)
[36] Songer et al. (2009)
[37] Black (2003, April)

9. Evidence-based Models. Students use technology to develop models based on data and evidence.

Developing and testing evidence-based models is a core practice that scientists use when investigating theories about the natural world. Engineers likewise rely on evidence-based models when they design systems and solutions that solve practical problems.[38] To develop a deep understanding of the practices that STEM professional use, students need to develop their own models based on data and evidence and the capacity to explain the evidence base and limitations of those models.[39] A clear example of how middle school students might use technology for developing and revising models is described by Krajcik and Merritt (2012). Sixth-grade students, for example, can use tablets or another technology tool to draw a model of how odor travels to the nose when learning about the movement of gasses and liquids. Students revise their model multiple times during an eight-week unit, making adjustments to the representation as they gain knowledge through inquiry activities where they explore the properties of gasses. As the unit progresses and students' knowledge increases, their models gradually become more consistent with the full scientific model. STEM instruction that fuses science content and practices in this way supports students in developing necessary skills to understand and engage in scientific inquiry process.

Cedars International Next Generation High School

Quick Facts

Location: Austin, TX (city, large)
FRPL: 48%
Black 20%
Hispanic: 57%
Asian: 5%
White: 15%
Other: 2%

Cedar International's Next Generation High School in Austin, Texas, embeds the development of evidence-based models into its project-based learning curriculum. Teachers often engage students with authentic design challenges, such as how to add additional space to the school building, a real and immediate problem facing the school. Students start by researching the spaces in the school, using abstract measuring tools and algebra to measure the dimensions of each of the rooms. Students use the data measurements to create a model for the existing school and then apply their algebraic skills to create another model for a new school design with more usable space. Students create drafts of floor plans and share them with a graphic design team. Together, both teams collaborate by asking questions back and forth about the specifics of the floor plan. When doing this project in the past, students used their hand sketches as models, but those models conveyed limited information. When students started using digital technology to generate models, their products became much more compelling, detailed, and articulate.

Watch the Cedars International Next Generation High School video!

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[38] National Academy of Engineering and National Research Council (2014)
[39] Krajcik & Merritt (2012)

Conclusion

Technology plays a central role in STEM professions and our everyday lives. So, while a strong STEM education supported by technology is valuable for young people who intend STEM careers, it is essential that everyone has access to STEM learning opportunities enhanced by technology that prepare them for life and work in today's complex world.

Numerous opportunities for STEM learning with technology exist in both formal and informal educational experiences at all levels of our education system. However, as in all fields of study, technology alone is not sufficient to make a difference in STEM. For powerful learning to occur, teachers must be able to make instructional decisions based on evidence that a particular approach will improve outcomes.

A systematic review of the research literature on the impact of technology in STEM learning, summarized in this report, identified nine dimensions practices that result in powerful learning. The nine dimensions, with examples of ways in which they are being used in classrooms across the country, can help teachers make effective decisions about how to support STEM learning with technology now and in the future.

References

Note: Below is the complete list of references that informed the development of the nine dimensions. Only those cited in the report include footnotes.

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Appendix: Methodology

When reviewing the scholarly literature, we focused our efforts on research that uses an experimental or quasi-experimental design to test the impacts of an intervention (e.g., a curricular unit or instructional approach) on student learning outcomes. We also included studies that were suggested by recognized experts in the field of STEM education.[40] A number of the Pathway Objects described in the Charting a Course for Success report further supported the STEM dimensions. These include "Make computational thinking an integral element of all education" (Dimension 6), "Encourage transdisciplinary learning" (Dimension 7), and "Expand digital platforms for teaching and learning" (Dimensions 1-9).

Identification of relevant studies

In our search we consulted the EBSCO, ERIC, and ProQuest databases along with the search engine Google Scholar. The Stanford University librarian recommended these databases because they are the largest resource collections relevant to education. Scholarly peer-reviewed work and grey literature (e.g., conference proceedings, dissertations and theses, technical reports, white papers, etc.) that were published in English between 2010-2018 and listed "education" as the subject (keyword) were included in the search. Additional search criteria included one or more keywords from each of the categories listed in Table 1, below. We also examined resources produced by the Department of Education's Policy and Program Studies Service (PPSS), the Institute for Education Sciences (IES) and sources cited by key STEM policy documents. For PPSS, every resource within the "Educational Technology" subsection within the "K-12 Instructional and Improvement Strategies" section was reviewed for relevance. For IES, every resource from 2010-2018 that contained "technology" in the title was reviewed for relevance.

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Table 1. Search keyword list

School level	Subject area*	Digital technology
High school	STEM	Educational technology
Secondary	Science	Digital learning/technology
Middle school	Match	Simulation/animation
Elementary	Mathematics	Digital games
Kindergarten	Engineering	Immersive environments
First grade, second grade...	Computer science	Probeware
Grade 1, grade 2, ...	Computational thinking	Models or modeling
	Technology	2D or 3D design software
		3D printer
		Programming
		Virtual labs/reality/field trips
		Video, video editing
		Podcast, audio recording
		Makerspace
		Mobile devices
		Applications/apps
		AI or Augmented reality
		Engineering technology/ design

*Among studies identified with these keywords, we will prioritize those that include the phrase "project-based learning," "problem-based learning" and/or "inquiry-based learning."

Coding of eligible studies

Studies that were coded for the research review were first screened according to established criteria. To be eligible for inclusion a study needed to:

- Examine students' learning or mastery of STEM content or practices through using/integrating one or more digital technologies in K-12 STEM and/or computer science classroom contexts;
- Report learning outcomes in STEM and/or computer science using an objective measure (see Table 2); and
- Provide enough statistical information to support a judgment of whether or not the study would meet WWC standards with or without reservations.[41]

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[41] Studies that would not meet WWC standards were not discarded, but were flagged. Each study was coded as "Appears to meet WWC standards," "Appears to meet WWC standards with reservations," or "Does not meet WWC standards."

Studies that were retained for the review after screening were coded using a study review template that was designed for this purpose. When selecting studies to include in the review, attention was paid to the following:

- Inclusion of studies that represent a broad range of student subgroups including rural, urban, minorities, girls, and historically underrepresented groups in STEM, etc.;
- Inclusion of studies with positive/successful outcomes when reviewing studies with an objective assessment; and
- Studies where technology was used to directly support students' development of STEM/computer science knowledge or practices (see Table 2 for general categories).

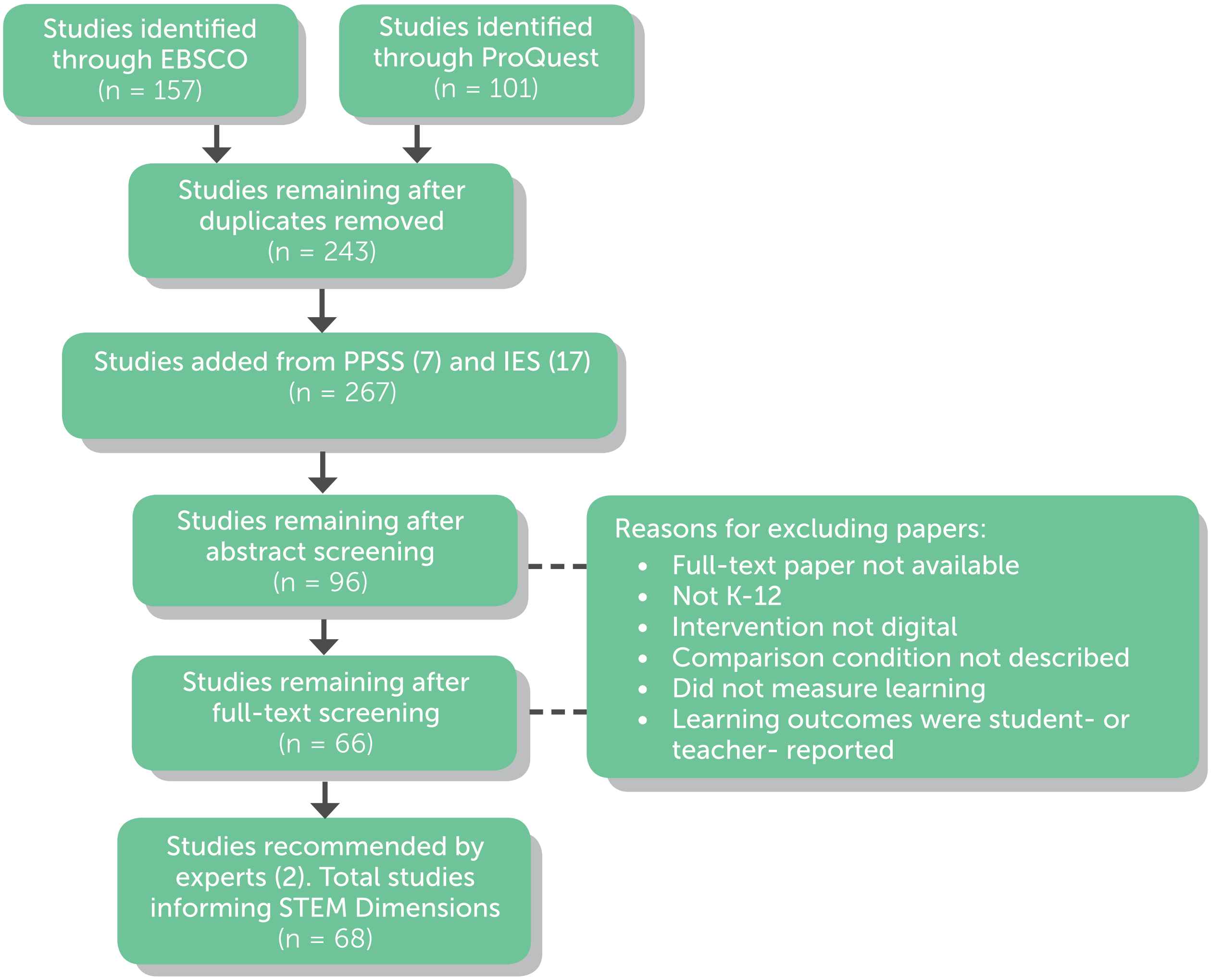
Table 2. Descriptions of STEM/computer science learning outcomes

STEM dimension	Sample outcomes
STEM/computer science knowledge (includes mastery and competency-based learning)	• Subject-specific knowledge and concepts (disciplinary core ideas and crosscutting concepts) • STEM/computer science interdisciplinary knowledge and concepts • Computational thinking
STEM/computer science practices	• Research-based STEM/computer science practices, for example: • Designing and conducting scientific experiments • Designing solutions through engineering or programming • Quantitative and/or abstract reasoning • Analyzing and interpreting data; arguing from evidence • Appropriate use of STEM/computer science tools • Effectively communicating STEM information • Modelling STEM phenomena

Results from study search

Our database and Google Scholar search yielded 264 articles (see Figure 1, below). The PPSS, IES, and STEM policy document review added four references. A review of the studies based on our eligibility criteria narrowed the research corpus to 64 studies that tested the effectiveness of a digital intervention in supporting an objectively measures STEM learning outcome. These studies were reviewed and discussed by the team to derive a tentative set of dimensions for the rubric.

Figure 1. Study search process for research synthesis



In our review we sought to identify studies that clearly described the link between technology use and students' STEM learning outcomes. Ideally, a study would provide enough description of the treatment condition to explain the role that technology played in facilitating students' STEM learning. These descriptions informed a number of emergent themes that ultimately became the first seven practices for supporting powerful STEM learning with technology. Feedback received from experts resulted in the addition of dimensions 8 and 9. Together with the spotlight videos, the nine dimensions provide teachers and school leaders with tangible examples of effective technology use for supporting powerful STEM learning.