Literature Review – NewSchools Ignite Middle & High School Science Challenge

Submitted to: NewSchools Venture Fund

Science, Technology, Engineering, and Mathematics (STEM) Program

WestEd

February 2017

WestEd.org

Overview

Technology has had a profound impact on science teaching. Educational technology delivers fundamental innovative changes that can be integral to achieving significant improvements in teaching and student understanding. Technologies have caused a paradigm shift in education away from a one-way flow of information (the teacher as the sage on the stage) to a collaborative interactive traffic of information and teaching between students and the teacher. Supporting both teaching and learning, educational technology can infuse classrooms with digital learning tools, such as computers and hand held devices; expand experiences, and learning materials; build 21 century skills; increase student engagement and motivation; and accelerate student learning. It can also be used to increase course offerings, and support learning anywhere and anytime.

Educational technology developers are creating online educational resources and other technologies that can increase educational productivity, e.g., by accelerating the rate of learning. Developers and researchers alike can draw on findings from education research studies and from practice guides written to orient them to best practices available for learning. Conceptual, physical, and computation modeling are practices by which scientists create and communicate understanding of science systems. Online simulations can represent and permit investigations of causal, temporal, and spatial relationships in science phenomena. Simulations can also help students build mental models of scientific domains and allow students to visualize concepts that appear on textbooks or hear from their teachers in lectures. Games can be used to engage students to explore scientific principles in open exploration environments more amenable to learning that normal classroom activities. Multiple forms of representations can be leveraged in these online materials to allow greater opportunity for students of varying language fluency and differing learning styles better access to the science materials and to express what they understand about scientific phenomena. The technology also enables teachers to quickly assess student understanding through formative assessment. Instruction materials that include a form of formative assessment driven both with and without intelligent tutoring systems to provide feedback are also a key target for educational technology developers.

Need

As the world becomes more technologically advanced, the need for computational reasoning and problem solving intensifies. Science proficiency is one of the major gateways for access to college, citizenship and economic access, and educators need access to instructional tools that will improve scientific understanding. According to Achieve, Inc., there is an *expectation gap*—a sizeable gap between what students knew leaving high school and the actual knowledge and skills they need to be successful in college and careers. In 2015, thirty-four percent of eighth-grade students performed at or above the *Proficient* level on the National Assessment of Educational Progress (NAEP) science assessment, which was 2 percentage points higher compared to 2011, the previous assessment year. Twenty-two percent of twelfth-grade students performed at or above the *Proficient* achievement level in science.

High school honors classes, Advanced Placement classes, International Baccalaureate and dual enrollment are four common programs that offer exposure to rigorous science curriculum that has been linked to success in college. The AP program is the national standard for academic rigor and college readiness, providing high school students with the opportunity to take college-level courses in a high school setting. AP courses provide the level of rigor that best prepares students for post-secondary success. One study found that students who took AP courses were significantly more likely to graduate from college compared with those who did not take an AP course. The gains were particularly noteworthy for some minority and low-income students. For African-Americans, only 10 percent of those who did not take an AP course graduated in five years, compared with 37 percent of those who took an AP course but did not pass the exam and 53 percent of those who took an AP course and passed the exam. Comparable results exist for Hispanic and low-income students. Research has found that AP students and, particularly, successful AP students, are more likely to perform well in college than non-AP students. Patterson and Ewing found that once in college, AP students performed as well as or better than the non-AP students in terms of subsequent college course grades. Research also supports that students who take AP classes in calculus and the sciences are more likely to select majors in careers such as engineering, science, and mathematics.

Science achievement in the U.S. is not keeping pace with international performance either. Comparative data show that U.S. students perform at or below average relative to students of many industrialized nations. On the most recent 2015 Programme for International Student Assessment (PISA), given every three years among 15-year-olds in dozens of developed and developing countries, U.S. students placed an unimpressive 24th out of 71 countries in science. Younger American students fared somewhat better on a similar cross-national assessment, the Trends in International Mathematics and Science Study (TIMSS) which tests students in grades four and eight. In the TIMSS study from 2015, 7 countries (out of 48 total) had statistically higher average fourth-grade science scores than the U.S. In the eighth-grade tests, seven out of 37 countries had statistically higher average science scores than the U.S. It is noteworthy that U.S. students who "failed" the AP Calculus exam still outperformed students from all other industrialized countries on the Trends in Mathematics and Science Study (TIMSS).

Best Practices in Science Education

There is now extensive research in the cognitive and learning sciences about how people learn. This research has resulted in a set of translation-ready principles that are relevant for informing instructional design decisions in educational settings. In particular, the Institute of Education Sciences (IES) Practice Guide, *Organizing Instruction and Study to Improve Student Learning,* lists a set of research-based recommendations for improving instruction and student learning in classroom contexts. A number of additional research-based best practices for teaching science have been identified and described in the research literature. Each research-based recommendation is considered a learning principle in that 1) it is broadly applicable to educational domains, and 2) has demonstrated effectiveness in both laboratory and classroom studies. As has been noted in the literature, there have been challenges in translational research, i.e., in taking cognitive learning principles and putting them into applied practice. There is a tension between basic and applied research, although these can be framed as two ends of a continuum having overlapping goals. The goal of basic research is to contribute to theory, and the goal of applied research is to contribute to practice.

Among those most applicable to the design and development of science education technology are:

Space Learning Over Time. Across many studies in cognitive science, students exhibit retention advantages when they are exposed to facts, concepts, or procedures at multiple points over time. This principle, known as "the spacing effect", has been widely demonstrated both in laboratory studies as well as classroom studies aimed at improving understanding of academic content and performance. Studies have also repeatedly found that memory is enhanced for information that is tested, known as the "testing effect". In other words, spacing is a structural design principle, and certain other activities such as quizzing can be slotted into that structure. Having to recall information helps students to commit that information to memory, thereby reducing the likelihood that students will forget that information. Research on the spacing effect suggests there is little disadvantage to interspersing long periods of spacing, suggesting that the exact spacing period is less important than re-exposing students to key content at later points.

Use Quizzing to Promote Learning. Research suggests that quizzing activities are successful in part because they prompt students to recall information, reflect on the state of their knowledge and understanding, and offer opportunities to transfer knowledge to new problems or situations. Feedback, revision, and reflection are also important aspects of meta-cognition and as such are critical to developing the ability to regulate personal learning. The quizzes can serve both as opportunities for the students to revisit concepts that they were exposed to in prior lessons, as well as serve as formative assessment opportunities.

Periodic testing provides students with opportunities to practice retrieving knowledge and using skills and concepts. It has long been known that practice alone without knowledge of results is much less effective than practice with feedback on how to adjust performance. However, learners may lack the knowledge to generate their own feedback and may waste time practicing incorrect skills. Well-designed cycles of feedback and reflection with opportunities for revision and knowledge updating can support students in practice that leads to mastery of the desired skills and concepts. Much of the work cited in support of the beneficial effects of quizzing and testing comes from laboratory studies focused on content that is largely declarative in nature with relatively few studies of the types of content and skills represented by school subject matter.

There is a substantial body of evidence from classroom learning contexts showing that the *formative* use of assessment can enhance instructional effectiveness; here, formative assessment is defined as a process used by teachers and students that provides feedback to adjust ongoing teaching and learning to improve students' achievement of intended instructional outcomes. Nyquist examined the role of feedback in formative assessment in a meta-analysis of over 100 studies that manipulated levels of feedback on tests administered within instructional settings. Across studies, the more detailed the feedback, the more students profited from having been tested. Directive and clear feedback, which included correct results combined with activities to correct errors, resulted in over half a standard deviation of improvement in student learning. These findings are consistent with the synthesis of research on formative assessment reported in Black & Wiliam. Wiliam suggests that using assessment formatively may be the most consequential component in the effectiveness of any instructional program. Educators are only beginning to understand the power of formative assessment, most especially the conditions of use to strategically improve instructional practice and student learning.

Structure Practice to Interleave Worked Examples and Problem-Solving Exercises. Cognitive theories of skill acquisition place great importance on practice because it leads to fluency and a reduction in the amount of processing resources needed to retrieve knowledge and execute a cognitive skill. In worked example exercises, students study solutions rather than solve problems themselves. Using a worked example involves having a student study a problem that has already been solved so that the student can understand the steps involved in arriving at the solution or result. There is now wide consensus of that combining the use of worked examples and practice problems in instruction leads to more effective *and* efficient learning than just practice alone. Interestingly, worked examples are effective for supporting learning even when the solutions are *incorrectly* worked out. The benefits of worked examples stem from their ability to focus student attention on the most relevant aspects of problems, a critically important goal given limitations in students' working memory capacity. Coupling worked examples with opportunities to self-explain the examples helps students to organize their knowledge and discover underlying principles. Coupled with feedback and opportunities, these worked example opportunities provide a powerful way of confronting student misconceptions about science concepts, as well as the scientific inquiry process.

Combine Graphics with Verbal Descriptions. Representations can be powerful aids to student learning. Research indicates that students learn most effectively when both graphics and verbal descriptions are used to present information relative to either graphics or text alone. Combining graphics with verbal descriptions supports at least two important aspects of science learning: 1) it ensures that text for instruction is perceived and understood, and 2) it promotes fluency in mapping between the representations. The multimedia learning literature has demonstrated that adding relevant diagrams and pictures to text-based materials leads to better learning than text alone. Comparison making between graphics and text is most efficient when corresponding text and graphics are placed close in proximity and when unnecessary details are omitted. It is important to present information in close proximity, and look for opportunities to prompt comparisons between multiple graphics.

A second function of combining graphics with verbal descriptions is to promote fluency in mapping between representations. It is recognized in science education research that students need to understand and link different representational modes including graphic and verbal modes to think and act scientifically. Different representations of the same concept provide access to different information and possibilities. Students who recognize relationships between various representational modes demonstrate better conceptual understandings than students who lack this knowledge.

Combining graphics with verbal descriptions can be applied to various aspects of a curriculum including learning materials, practice exercises, and classroom instruction. Graphics and verbal descriptions can be effectively combined in instructional materials by highlighting relationships using proximity (e.g., verbal labels on aspects of diagrams or graphs), color (e.g., highlighting corresponding aspects of related representations in the same color), or other forms of connections (e.g., arrows to connect corresponding aspects of representations). These studies suggest that combining graphics with verbal descriptions by carefully directing student attention to the appropriate correspondences and providing guidance to teachers on appropriate instructional moves are promising approaches to guide the design of science curriculum and instructional resources. This principle can be applied to text materials, practice activities, and recommendations for teachers.

Connect and Integrate Abstract and Concrete Concepts. Connecting and interleaving concrete and abstract representations has been shown to support robust learning of many concepts in science. To balance the benefits of each representational type, science concepts can be presented initially as concrete representations and gradually fade the concreteness of representations over time with more idealized, abstract representations, a process known as "concreteness fading".

Use Contrasting Cases to Differentiate Student Knowledge and Confront Misconceptions. Contrasting cases consist of examples that share a common set of relationships, but that differ either in the concrete features that instantiate the relations, or in the relations themselves (e.g., the evolution of finches and iguanas share common relationships related to the mechanism of evolutionary change, but differ in the specific adaptations these species adopted over time). Though not explicitly listed as a recommendation in the IES practice guide, there is strong evidence that prompting comparisons between contrasting cases can lead to improved student learning. Schwartz and Bransford revealed that when students engage in comparison of contrasting cases, their knowledge becomes differentiated for essential concepts, resulting in students being better prepared to learn from explicit instruction. Even if students do not arrive at correct conclusions, they still benefit from later instruction in the topic. The practice of prompting comparisons between contrasting cases can also be used to confront student misconceptions. By presenting both correct and incorrect conceptions, the student engages in a relational alignment process that highlights both the critical differences as well as the similarities between the conceptions. This process allows students to engage in deep theory level explanations.

Help Students Build Understanding by Answering Deep Questions. Deep questions refer to questions that foster explanations of causal mechanisms and can be answered by forming logical arguments. Examples of deep questions might be "*How does the evolution of iguanas compare with that of finches?"* or *"What is the evidence for the similarities or differences between their evolution?*" Research has consistently found that use of deep questions leads to robust learning and improved academic learning outcomes. Providing students with opportunities to engage in explanation of deep questions fosters active learning and allows students to organize their knowledge as well as discover underlying principles. Encouraging students to self-explain concepts can be a particularly powerful way to support conceptual change and to confront misconceptions.

Professional Development and Support. Professional development on the use of science instructional materials should draw on principles of effective professional development. These works suggest that professional development must be consistent with local curriculum and standards and focus on strengthening teachers' content and pedagogical content knowledge. Also, there is mounting evidence that the duration of the professional development and the building of a community of learners contributes to teacher learning, change in practice, and increases in student learning. Teachers as learners need time to activate their prior knowledge, instruction that builds deep understanding of key ideas and to make connections to supporting concepts and facts, and they need to be metacognitive about their learning. Professional development begins by activating what teachers already know about the content and strategies they will learn.

Applying Educational Technology to Science Learning

Technology has the power to transform teaching by introducing new models of connected teaching. These technologies include a host of Web 2.0 online tools that foster communication, collaboration, social and learning networks, as well as accessing information. They also include interactive whiteboards, tablet PCs, projectors and other tools that allow schools to present information in ways that encourage discussion and collaboration. These models can link teachers to their students and to professional content, resources, and systems to help them improve their own pedagogy as well as to individualize learning for their students. Online educational resources and other technologies can also increase educational productivity, e.g., by accelerating the rate of learning.

The digital divide is closing. Connectivity and access will soon be a non-issue in K-12 students' ability to engage in digital learning. President Obama's ConnectED 2013 initiative, tasks the Federal Communications Commission (FCC) with connecting 99% of America's K-12 students to gigabit broadband and robust Wi-Fi by 2018. This will transform the classroom experience for all students, regardless of income. "Between 2015 and 2020, hardware, software, and network technologies will mature sufficiently such that educational technology's Holy Grail for K-12--a computing device--a mobile device--for every child, 24/7--will be realized". Stevenson et al., propose that smart mobile devices provide "situated, authentic and connected" learning experiences and that apps should be explored as "cognitive stepping stones".

In some cases, technology has taken the place of an actual teacher through distance learning. As a study from the National Center for Education Statistics (NCES) reports, "During the 12-month 2004–05 school year, 37 percent of public school districts had students in the district enrolled in technology-based distance education courses. This represents an estimated 5,670 of a total 15,190 public school districts in the country" (p. 9). "Technology-based distance education courses are considered the future of distance education offerings, with online technologies looked upon by some policymakers as offering the greatest promise". According to a report by the North American Council for Online Learning (NACOL), "As of September 2007, 42 states [had] significant supplemental online learning programs (in which students enrolled in physical schools take one or two courses online), or significant full-time programs (in which students take most or all of their courses online), or both".

Prior research in cognition and science learning suggests that key features of effective science educational technology support activities that are highly likely to promote student learning. These include: active participation, integrating visual and verbal information, and improved teacher pedagogical content knowledge. They also include other features (formative assessment, scientific inquiry, use of simulations to model real-world phenomena, and connecting abstract and concrete representations) that will be discussed in the section on developing educational technology for science.

In-the-moment Formative Assessment. A classroom response system (CRS) is an instructional technology that helps an instructor pose questions and poll students' answers during class. Technology-enhanced formative assessment (TEFA) is a pedagogy that can be used for CRS-based science instruction. TEFA allows teachers to integrate assessments into the learning environment by posing questions and receiving responses wirelessly from all students simultaneously. A CRS involves a set of input devices for students, communicating in some way with software running on the instructor's computer can easily be deployed in the classroom. These devices are often simple handheld keypads called "clickers" that transmit data to the instructor's computer via infrared or radio-frequency signals. Students select a response to a multiple-choice, numeric or free-text question. The displayed responses can be displayed in multiple ways (individual, aggregated, various charts) always maintaining anonymity for individual students. Clickers can be used effectively for real-time polling by instructors to implement teaching methodologies into their classroom that will enhance their students' learning transfer. At the same time, the instructor is able to instantly see who has understood the content and who has not. Research has shown that TEFA can be highly effective, often transformative, for science instruction. By facilitating immediate feedback in a public, non-threatening forum, it supports formative assessment as well as scientific discourse in the classroom.

Thus this technology allows the teacher to use quizzing to re-teach key content. Research suggests that quizzing, questioning, and assessment activities enhance student learning because they prompt students to recall information, reflect on the state of their knowledge and understanding, and offer opportunities to transfer knowledge to new problems or situations. Self-regulated learning principles of feedback, revision, and reflection are also critical to developing the ability to monitor and improve personal learning. Beatty posits that connected classroom communication systems enable students to be active participants in the learning process by integrating new knowledge and overcoming misconceptions.

Integration of Verbal with Visual Information. One affordance of education technology is the use of highly graphic and interactive modes to promote more frequent integration of visual and verbal information during instruction. Multiple representations can enhance learning, particularly when students are actively engaged in processing and linking the representations. In particular, combining graphics with verbal descriptions increases learning, presumably because encoding of information is enhanced when information is processed simultaneously through visual and auditory sensory channels. Further, dynamic displays have been shown to increase student understanding of complex processes when they are used in conjunction with activities that support comprehension.

Facilitating Productive Scientific Discourse and Encouraging Active Participation. In a networked environment, learning is promoted through mutual collaboration. Teachers encourage students to formulate and test their ideas with other students and to frequently assess how an activity is helping them gain science understanding. Research studies using audience response systems (ARS) in student-centered learning environments show conceptual gains.

Improving Pedagogical Content Knowledge. Professional development is considered an essential mechanism for deepening teachers' content knowledge and developing their teaching practices. Professional development programs aimed at the development of teachers' PCK and TPACK, should be closely aligned to teachers' professional practice. Professional development should engage teachers in aligning activities to specific science content in their classrooms with the potential to develop teachers' TPACK and support integration of education technologies in their classrooms.

Education technology can support these activities through networked technology and teacher professional development. Education technology enables formative assessment in the form of online interactive scientific explorations, polls and quizzes; simulation software supports inquiry-based learning, integration between multiple representations, as well as formative assessment. Technology also allows the anonymous sharing of student and group responses. In professional development, teachers can build their content understanding working with the technology as a learner, then shift and build their pedagogical content knowledge (PCK) by examining common classroom situations, analyzing student work, and planning for their own instruction. Building PCK can thus be extended to technology pedagogical content knowledge (TPACK).

Developing Educational Technology for Science Learning

Technology has equally transformed the way in which science is conducted. Almost every aspect of scientific exploration has been touched in some way by technology, and much of today's science would not be possible without it. The mapping of the human genome, astronomical observation, weather forecasting, and the development of emerging nanotechnologies are all dependent upon information technology.

Conceptual, physical, and computation modeling are practices by which scientists create and communicate understanding of science systems. Simulations can represent and permit investigations of causal, temporal, and spatial relationships in science phenomena. Simulations can help students build mental models of scientific domains and allow students to visualize concepts that appear on textbooks or hear from their teachers in lectures. Using a simulation where the students are able to vary parameters and see the effect of these variations, the role of equations is powerfully enriched. Simulations contain physical systems represented in many different ways in two or three-dimensions: pictures, graphs, words, equations, diagrams, data tables, contour maps, etc. The students can make sense of the concepts by seeing the connection between the representations and how one variable affects another.

Simulations have been harnessed to both portray dynamic science systems "in action" and to allow active scientific investigations. Simulations can also expand ways students show what they know by offering response formats such as hot spots, drag and drop, drawing, operating sliders, and generating graphics, tables, and visualizations. These expanded modalities of representation and expression offer great promise for reducing language demands and increasing access for students with disabilities and English learners. Simulations can represent content in multiple forms, reducing language demand for low performing students, English learners (ELs), and students with disabilities (SWD). For instance, researchers have demonstrated that students performed better on the simulation benchmark assessments than on the traditional posttest items, and performance gaps between both English Learners (EL) and students with disabilities (SWD) compared to other students were reduced on the benchmark, suggesting that more visual representations and less text may allow EL and SWD students to better demonstrate their science content knowledge and particularly their science inquiry practices.

The SimScientists simulation-based modules target core science principles and practices called for in the new *Framework for K-12 Science Education,* yet addressed inadequately by conventional formats. These next-generation digital materials focus on cross-cutting concepts of systems thinking and model-based learning, and, in particular, active deployment of science practices such as using models to predict, collect, analyze and interpret evidence, and constructing and critiquing arguments. The tasks probe developmental progressions across levels of a science system using representations that move from concrete depictions of phenomena to invisible features and processes and dynamically generated system behaviors. These system models provide a framework to help students reorganize typically inert, disconnected factual knowledge and procedural skills.

As discussed in a recent IES Practice Guide, instructional tools can help anchor instruction and help students make sense of content and conceptual ideas. Studies have shown that instructional tools used in science classrooms can help students learn important concepts and facilitate their understanding of the content. Instructional tools included short videos, visual representations of vocabulary and concepts, and graphic organizers and were used in content-area classes to support English learners.

Formative Assessment. Formative assessment is the use of assessment, in which the results of the assessment are used to modify instruction, can enhance instructional effectiveness. Educators recognize and understand the power of formative assessment, especially the conditions of use to strategically improve instructional practice and student learning. Without prompt feedback, learners may waste time practicing incorrect skills. Teachers who use education technologies receive student responses immediately and can adjust their instruction in the moment. Using interactive technologies empowers the teacher to leverage students' prior knowledge, assess conceptual understanding, and attend to student learning through questions and answers with immediate feedback. The challenge for educational technology developers is to create online systems and materials that provide real-time customized feedback and coaching for students as well as reports for teachers to guide their understanding and efforts to implement appropriate follow-up instruction where needed as described in the following sections.

Computer Simulations to Support Science Instruction and Learning. Advances in educational technology have been combined with improved understanding of student's cognitive development to produce empirically validated curriculum for introducing various science concepts in middle school grades. Models allow students to manipulate unseeable worlds—atoms and molecules, forces and motion, and genetic variation, to name a few. Simulations can also be used to compress centuries into seconds to access an understanding of rock and land formations. In short, models and simulations hold unprecedented ability to help students learn. Computer-based, manipulable models of interacting components have been used to help students understand interactions among the components, and to development an understanding of the emergent behaviors of the system. Educators have created research-based curricula centered on progressively complex models that exhibit such emergent behavior. Online modules allow them to log students' actions as they interact with the models, analyzing such performance data to infer the students' understanding. Their research is helping to improve the teaching of complex scientific ideas and to provide a reliable means of directly assessing students' conceptual understanding and inquiry skills, as opposed to their recall of science "facts."

Computer Games to Support Science Instruction and Learning. Online games have been used successfully to engage students in better understanding complex science phenomena. Radix Endeavor is representative of a massively-multiplayer online role playing game (MMORPG) that immerses players in an earth-like fantasy world. The game environment tasks students with solving situational-based tasks that involve multiple domains including ecology, evolution, genetics, and human body system. Teachers can assign tasks to their students through a dashboard interface and follow their progress throughout the game. Additionally, the online game website offers teachers tools for incorporating the game into the larger class curriculum structure. Other games such as Kerbal Space Program, MetaboSIM, and GlassLab Games have been used in the classroom to reinforce content in diverse science domains.

Stealth assessment is a tool that uses evidence-centered design (ECD) to create assessments that are integrated seamlessly into the gaming environment. During gameplay, rich data is produced by students completing complex tasks involving the skills and competencies being assessed such as scientific inquiry. The output from the assessment is transparent, and students should be aware of how they are performing relative to the defined competencies. In order to ensure that the results are valid and reliable, the assessment must be unobtrusive in order to keep the student engagement intact. Physics Playground is an example of a game where stealth assessment has been applied successfully. This 2-dimensional physics game tasks students to apply various Newtonian principles as they create and guide a ball to a red balloon placed on screen. The player moves the ball by drawing with colored markers to create simple machines called agents of force and motion in the game. Everything obeys the basic rules of physics relating to gravity and Newton's three laws of motion.

Simulations Connecting Abstract and Concrete Representations. Education technology allows teachers and students to directly interact with computer simulations of scientific phenomena. Abstract relationships can be concretely depicted through animations of processes. For example, *amplitude* and *frequency* are key terms that students need to understand about waves. When the graphic representation of a wave is presented, it may still appear as an abstract manifestation of the phenomenon. By explicitly combining this representation dynamically with a representation of as associated physical manifestation of a wave, such as an earthquake or heat in a solar oven, students can see and manipulate parametric values with concrete results. This allows for opportunities to see the connections among the different types of representations that further support the development of a deeper understanding by making connections with concrete and abstract examples. Learning is enhanced when learners connect and interleave abstract and concrete representations. The dynamic visual display can also more readily support perceptual-motor grounding through dynamic demonstrations and hands-on, student-directed manipulation. Research suggests that learning is enhanced when complex concepts are initially grounded in a perceptual-motor experience.

References

Abrahamson, L. (2006). A brief history of networked classrooms: Effects, cases, pedagogy, and implications *Audience response systems in higher education: Applications and cases* (pp. 1-25): IGI Global.

Ainsworth, S. (1999). A functional taxonomy of multiple representations. *Computers and Education, 33,* 131-152.

Ainsworth, S. (2006). DeFT: A conceptual framework for learning with multiple representations. *Learning and Instruction, 16*(3), 183-198.

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge, MA: Harvard University Press.

August, D., Shanahan, T., & Escamilla, K. (2009). English language learners: Developing literacy in second-language learners—Report of the National Literacy Panel on Language-Minority Children and Youth. *Journal of Literacy Research, 41*(4), 432-452.

Baker, S., Geva, E., Kieffer, M.J., Lesaux, N., Linan-Thompson, S., Morris, J., Proctor, C. P., & Russell, R. (2014). Teaching Academic Content and Literacy to English Learners in Elementary and Middle School. IES Practice Guide. NCEE 2014-4012. *What Works Clearinghouse*.

Baldi, S., Jin, Y., Skemer, M., Green, P. J., & Herget, D. (2008). *Highlights from PISA 2006: Performance of U.S. 15-year-old students in science and mathematics literacy in an international context* (NCES 2008-016). Washington, DC: National Center for Education Statistics.

Banks, D. A. (2006). Reflections on the use of ARS with small groups. *Audience response systems in higher education*, 373-386.

Baxter, H., & Lauffer, D. (2007, October). The SIMPL approach to science education reform. Unpublished manuscript. Madison, WI: University of Wisconsin-Madison, Wisconsin Center for Education Research.

Beatty, I. (2004). Transforming student learning with classroom communication systems. *Educause Center for Applied Research*. *Research Bulletin, 3*(5).

Beatty, I. D., Feldman, A., Leonard, W. J., Gerace, W. J., Cyr, K. S., Lee, H., & Harris, R. (2008). Teacher learning of technology-enhanced formative assessment. Paper presented at the Annual International Conference of the US National Association for Research in Science Teaching (NARST), Baltimore, MD.

Beatty, I., & Gerace, W. (2009). Technology-Enhanced Formative Assessment: A Research-Based Pedagogy for Teaching Science with Classroom Response Technology. *Journal of Science Education and Technology, 18*(2), 146-162.

Bennett, R. E. (2011). Formative assessment: A critical review. *Assessment in Education: Principles, Policy & Practice, 18*(1), 5-25.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7-74.

Blank, R. K., & de las Alas, N. (2009). Effects of teacher professional development on gains in student achievement. (Tech. Report). *Meta-Analysis Study of the Effects of Teacher Professional Development with a Math or Science Content Focus on Improving Teaching and Learning*. Washington, DC: Council of Chief State School Officers.

Bokosmaty, S., Sweller, J., & Kalyuga, S. (2014). Learning Geometry Problem Solving by Studying Worked Examples Effects of Learner Guidance and Expertise. *American Educational Research Journal*, 0002831214549450.

Bransford, J. D., Brown, A.L., & Cocking, R.R. (2000). How people learn: Brain, mind, experience, and school. Washington, DC: The National Academy Press.

Brunner, C., Fasca, C., Heinze, J., Honey, M., Light, D., Mandinach, E. (2005). Linking data and learning: The Grow Network study. *Journal for Students Placed at Risk*, *10*(3), 241-267.

Butler, A. C., & Roediger, H. L., III (2007). Testing improves long-term retention in a simulated classroom setting. *European Journal of Cognitive Psychology, 19*(4), 514-527.

Carpenter, S. K., Cepeda, N. J., Rohrer, D., Kang, S. H., & Pashler, H. (2012). Using spacing to enhance diverse forms of learning: Review of recent research and implications for instruction. *Educational Psychology Review*, *24*(3), 369-378.

Carpenter, S.K., Pashler, H., Cepeda, N.J., & Alvarez, D. (2007). Applying the principles of testing and spacing to classroom learning. In D.S. McNamara & J.G. Trafton (Eds.), *Proceedings of the 29th Annual Cognitive Science Society* (p.19). Nashville, TN: Cognitive Science Society.

Chajewski, M., Mattern, K. D., & Shaw, E. J. (2011). Examining the Role of Advanced Placement® Exam Participation in 4-Year College Enrollment. *Educational Measurement: Issues & Practice, 30*(4), 16-27.

Chi, M.T.H. (2009). Active-Constructive-Interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science, 1*(1), 73-105.

Chi, M.T.H., de Leeuw, N., Chiu, M.H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18*(3), 439-477.

Clark, R. C., & Mayer, R. E. (2016). *E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning*: John Wiley & Sons.

Clarke-Midura, J., Rosenheck, L., Haas, J., & Klopfer, E. (2013). The Radix Endeavor: designing a massively multiplayer online Game around collaborative problem solving in STEM. *Retrieved from https://www.radixendeavor.org/sites/default/files/radix.cscl_.2013.pdf*.

Coburn, C., & Talbert, J. (2006). Conceptions of evidence use in school districts: Mapping the terrain. *American Journal of Education, 112*(4), 469-496.

Craig, S.D., Sullins, J., Witherspoon, A., & Gholson, B. (2006). The deep-level-reasoning-question effect: The role of dialogue and deep-level-reasoning questions during vicarious learning. *Cognition and Instruction*, 24(4), 565-591.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis, 24*(2), 81-112.

Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational evaluation and policy analysis*, *24*(2), 81-112.

Dougherty, C., Mellor, L., Jian, S., & National Center for Educational, A. (2006). The Relationship between Advanced Placement and College Graduation. 2005 AP Study Series, Report 1.

Ewing, M., College Board, O. o. R., & Analysis. (2006). The AP® Program and Student Outcomes: A Summary of Research. Research Notes. RN-29. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED561027&site=ehost-live

Fies, C., & Marshall, J. (2006). Classroom response systems: A review of the literature. *Journal of Science Education and Technology, 15*(1), 101-109.

Frohbeiter, G., Greenwald, E., Stecher, B., & Schwartz, H. (2011). Knowing and doing: What teachers learn from formative assessment and how they use information. CRESST Report 802. Los Angeles: UCLA National Center for Research on Evaluation, Standards, and Student Testing.

Gadgil, S., Nokes-Malach, T.J., & Chi, M.T.H. (2012). Effectiveness of holistic mental model confrontation in driving conceptual change. *Learning and Instruction*, *22*(1), 47-61.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*(4), 915-945.

Gentner, D. (2010). Bootstrapping the mind: Analogical processes and symbol systems. *Cognitive Science, 34*(5), 752-775.

Glenberg, A. M., & Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9,* 558-565.

Glenberg, A. M., & Robertson, D. A. (1999). Indexical understanding of instructions. *Discourse Processes, 28,* 1-26.

Gobert, J. D., & Clement, J. J. (1999). Effects of student-generated diagrams versus student-generated summaries on conceptual understanding of causal and dynamic knowledge in plate tectonics. *Journal of Research in Science Teaching, 36*(1), 39-53.

Goldman, S. R. (2003). Learning in complex domains: When and why do multiple representations help? *Learning & Instruction, 13,* 239-245.

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *The Journal of the Learning Sciences, 14*(1), 69-110.

Gonzales, P., Williams, T., Jocelyn, L., Roey, S., Kastberg, D., Brenwald, S., & National Center for Education, S. (2008). Highlights from TIMSS 2007: Mathematics and Science Achievement of U.S. Fourth- and Eighth-Grade Students in an International Context. NCES 2009-001. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED503625&site=ehost-live

Graesser, A. C. (2009). Cognitive scientists prefer theories and testable principles with teeth. *Educational Psychologist, 44*(3), 193-197.

Graesser, A. C., & Person, N. K. (1994). Question asking during tutoring. *American educational research journal*, *31*(1), 104-137.

Heritage, M., & Wylie, E. C. (2010). Developing and deepening formative assessment practice. In M. Heritage, *Formative assessment: Making it happen in the classroom* (pp.117-132). Thousand Oaks, CA: Corwin Press.

Irving, K., Sanalan, V., & Shirley, M. (2009). Physical science connected classroom: Case studies. *Journal of Computers in Mathematics and Science Teaching, 28,* 247-275.

Jimoyiannis, A. (2010). Designing and implementing an integrated technological pedagogical science knowledge framework for science teachers professional development. *Computers & Education, 55*(3), 1259-1269.

Judson, E., & Sawada, D. (2002). Learning from past and present: Electronic response systems in college lecture halls. *Journal of Computers in Mathematics and Science Teaching, 21,* 167-181.

Kapur, M. (2009). Learning through productive failure in mathematical problem solving. In B. Kaur, Y. Ben Har, & M. Kapur (Eds.), *Mathematical Problem Solving* (pp.43-68). Singapore: World Scientific.

Kear, K., Woodthorpe, J., Robertson, S., & Hutchison, M. (2010). From Forums to Wikis: Perspectives on Tools for Collaboration. *Internet And Higher Education*, 13(4), 218-225.

Kennedy, M. M. (1999). *Form and substance in mathematics and science professional development*. Madison, WI: National Institute for Science Education.

Kim, M. C., Hannafin, M. J., & Bryan, L. A. (2007). Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science Education, 91*(6), 1010-1030.

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: Effects of direct instruction and discovery learning. *Psychological Science, 15*(10), 661-667.

Knight, J. K., & Wood, W. B. (2005). Teaching more by lecturing less. *Cell Biology Education, 4,* 298-310.

Koedinger, K. R., Corbett, A. T., & Perfetti, C. (2012). The knowledge-learning-instruction framework: Bridging the science-practice chasm to enhance robust student learning. *Cognitive Science, 36*, 757-798.

Lachat, M., & T. Smith. (2005). Practices that support data use in urban high schools. Journal of Education for Students Placed at Risk, 10(3): 333–349.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science: A Multidisciplinary Journal, 11*(1), 65-100.

Logan, J. M., Castel, A. D., Haber, S., & Viehman, E. J. (2012). Metacognition and the spacing effect: the role of repetition, feedback, and instruction on judgments of learning for massed and spaced rehearsal. *Metacognition and Learning*, *7*(3), 175-195.

Lombrozo, T. (2006). The structure and function of explanations. *Trends in Cognitive Sciences, 10*(10), 464-470.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics* (2nd ed.). Thousand Oaks, CA US: Corwin Press.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching *Examining pedagogical content knowledge* (pp. 95-132): Springer.

Markman, A.B., & Gentner, D. (1993). Structural alignment during similarity comparisons. *Cognitive Psychology, 25*(4), 431-467.

Matlen, B.J. (2015). Comparison-based instruction in facilitating higher-order understanding of experimental design. Published online for *The Annual Conference of the American Educational Research Association*.

Matlen, B.J., Vosniadou, S., Jee, B.G., & Ptouchkina, M. (2011). Enhancing the comprehension of science text through visual analogies. In *Proceedings of the 34th Annual Meeting of the Cognitive Science Society*. Austin, TX: Cognitive Science Society.

Mayer, R. E. (2001). *Multimedia learning*. London: Cambridge University Press.

Mayer, R. E. (2002). Multimedia learning. *Psychology of Learning and Motivation, 41*, 85-139.

Mayer, R. E. (2008). Applying the science of learning: evidence-based principles for the design of multimedia instruction. *American Psychologist*, *63*(8), 760.

Mazur, E. (1997). *Peer instruction: A user's manual*. Upper Saddle River, NJ: Prentice Hall.

McDaniel, M. A., Roediger, H. L., & McDermott, K. B. (2007). Generalizing test-enhanced learning from the laboratory to the classroom. *Psychonomic bulletin & review, 14*(2), 200-206.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017.

Mislevy, R., Oranje, A., Bauer, M., Davier, V. A., Hao, J., Corrigan, S., ... & John, M. (2014). *Psychometric Considerations in Game-Based Assessment*. Redwood City, CA: *GlassLab games*.

Moreno, R., & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology, 91(2),* 358-368.

Narayanan, N., & Hegarty, M. (2002). Multimedia design for communication of dynamic information. *International Journal of Human-Computer Studies, 57,* 279-315.

Nersessian, N. (2008). Model-based reasoning in scientific practice. *Teaching scientific inquiry: Recommendations for research and implementation*, 57-79.

Norris, C., & Soloway, E. (2015). Mobile Technology in 2020: Predictions and Implications for K-12 Education. *Educational Technology, 55*/1, 12-19.

Nyquist, J. B. (2003). *The benefits of reconstructing feedback as a larger system of formative assessments: A meta-analysis*. Unpublished master's thesis. Vanderbilt University.

O'Hara, M. (2012). Closing the Expectations Gap, 2012: 50-State Progress Report on the Alignment of K-12 Policies and Practice with the Demands of College and Careers. *Achieve, Inc*.

Paas, F.G., & van Merrienboer, J.J. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology, 86*(1), 122-133.

Pashler, H., Bain, P., Bottge, B., Graesser, A., Koedinger, K., McDaniel, M., & Metcalfe, J. (2007). *Organizing instruction and study to improve student learning* (NCER 2007-2004). Retrieved from Washington, DC: National Center for Education Research, Institute of Education Sciences, U.S. Department of Education.

Patterson, B. F., Ewing, M., & College, B. (2013). Validating the Use of AP® Exam Scores for College Course Placement. Research Report 2013-2. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=eric&AN=ED558108&site=ehost-live

Prain, V., & Waldrip, B. (2006). An exploratory study of teachers' and students' use of multi-modal representations of concepts in primary science. *International Journal of Science Education, 28*(15), 1843-1866.

Quellmalz, E. S., & Pellegrino, J. W. (2009). Technology and Testing. *Science, 323*(5910), 75-79.

Quellmalz, E. S., Silberglitt, M. D., & Timms, M. J. (2011). How can simulations be components of balanced state science assessment systems. San Francisco, CA: WestEd. Retrieved from http://www. wested. org/cs/we/view/rs/1198.

Robinson, M. (2003). Student Enrollment in High School AP Sciences and Calculus: How does it Correlate with STEM Careers? *Bulletin of Science, Technology & Society, 23*(4), 265-273.

Roediger, H. L. & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Science, 17*(3), 249-255.

Rohrer, D. (2009). The effects of spacing and mixing practice problems. *Journal for Research in Mathematics Education, 40*(1), 4-17.

Rohrer, D., & Taylor, K. (2006). The effects of overlearning and distributed practice on the retention of mathematics knowledge. *Applied Cognitive Psychology, 20*(9), 1209-1224.

Ronau, R., & Rakes, C. (2011). A comprehensive framework for teacher knowledge (CFTK): Complexity of individual aspects and their interactions. In R. N. Ronau, C. R. Rakes, & M. L. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches* (pp. 59-102). Hershey, PA: IGI Global.

Roschelle, J., Penuel, W., & Abrahamson, L. (2004). The networked classroom. *Educational Leadership*, *61*(5), 50-54.

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of Educational Research, 66*(2), 181-221.

Russell, M. K. (2010). Technology-aided formative assessment of learning: New developments and applications. In H. L. Andrade and G. J. Cizek (Eds.), *Handbook of formative assessment* (pp. 125-138). New York: Routledge.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Bulletin, 84*(1), 1-66.

Schneider, W., Dumais, S. T., & Shiffrin, R. M. (1984). Automatic and control processing and attention. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of attention* (pp. 1-27). Orlando, FL: Academic Press.

Shute, V. J. (2011). Stealth assessment in computer-based games to support learning. In S. Tobias & J. D. Fletcher (Eds.), *Computer games and instruction* (pp. 503-524). Charlotte, NC: Information Age Publishers.

Shute, V. J., Ventura, M., Bauer, M., & Zapata-Rivera, D. (2008). *Monitoring and fostering learning through games and embedded assessments* Princeton, NJ: Educational Testing Service.

Schwartz, D.L., & Bransford, J.D. (1998). A time for telling. *Cognition and Instruction, 16*(4), 475-522.

Schwartz, D.L., & Martin, T. (2004). Inventing to prepare for future learning: The hidden efficacy of encouraging original student production in statistics instruction. *Cognition and Instruction, 22*(2), 129-184.

Schwartz, D.L., Chase, C.C., Oppezzo, M.A., & Chin, D.B. (2011). Practicing versus inventing with contrasting cases: The effects of telling first on learning and transfer. *Journal of Educational Psychology, 103*(4), 759-775.

Siegler, R.S. (2002). Microgenetic studies of self-explanation. In N. Grannot & J. Parziale (Eds.), *Microdevelopment: Transition processes in development and learning* (pp.31-58). Cambridge, UK: Cambridge University Press.

Silverman, R., & Hines, S. (2009). The effects of multimedia-enhanced instruction on the vocabulary of English-language learners and non-English-language learners in pre-kindergarten through second grade. *Journal of Educational Psychology, 101*(2), 305.

Squad (2011). Kerbal Space Program [online game]. *Retrieved from https://kerbalspaceprogram.com/en/.*

Stevenson, M., Hedberg, J., Highfield, K., & Diao, M. (2015). Visualizing Solutions: Apps as Cognitive Stepping-Stones in the Learning Process. *The Electronic Journal of e-Learning, 13*(5), 366-374.

Stover, S., Noel, D., McNutt, M., & Heilmann, S. (2015). Revisiting use of real-time polling for learning transfer. *Journal of Teaching and Learning with Technology, 4*(1), 40-60.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*(9), 963-980.

Sweller, J., & Cooper, G.A. (1985). The use of worked examples as a substitute for problem solving in learning algebra. *Cognition and Instruction, 2*(1), 59-89.

The White House. (2013). ConnectED: President Obama's Plan for Connecting All Schools to the Digital Age. Retrieved from https://eric.ed.gov/?q=Obama%27s+ConnectEd+initiative&ff1=souThe+White+House&ff2=pubReports+-+Descriptive&id=ED557424

Thorndike, E. L. (1913). *An introduction to the theory of mental and social measurements*. New York: Teacher's College, Columbia University.

Tversky, B. (2003). Some ways graphics communicate. In K. Nyiri, Editor. *Mobile communication: Essays on cognition and community* (pp. 143-156). Wien: Passage.

U.S. Department of Education. (2016). National Assessment of Educational Progress (NAEP), 2015 Science Assessments. Washington, DC: Institute of Education Sciences, National Center for Education Statistics. Retrieved August 2016 from http://nces.ed.gov/nationsreportcard/science/.

Van Driel, J. H., & Berry, A. (2012). Teacher Professional Development Focusing on Pedagogical Content Knowledge. *Educational Researcher, 41*(1), 26-28.

Van Gog, T., Kester, L., & Paas, F. (2011). Effects of worked examples, example-problem, and problem-example pairs on novices' learning. *Contemporary Educational Psychology*, 36(3), 212-218.

Watson, J. (2008). Blended Learning: The Convergence of Online and Face-to-Face Education. Promising Practices in Online Learning. *North American Council for Online Learning*.

Watson, J. F. (2007). A National Primer on K-12 Online Learning. *North American Council for Online Learning*.

Wayman, J. C., & Stringfield, S. (2006). Technology-supported involvement of entire faculties in examination of student data for instructional improvement. *American Journal of Education, 112*(4), 549-571.

Weiss, I. R., & Pasley, J. D. (2006). *Scaling up instructional improvement through teacher professional development: Insights from the local systemic change initiative* (CPRE Policy Brief RB-44). Madison, WI: Consortium for Policy Research in Education.

William, D. (2007). Keeping learning on track: Formative assessment and the regulation of learning. In F. K. Lester Jr. (Ed.), Second handbook of mathematics teaching and learning (pp. 1053-1098). Greenwich, CT: Information Age Publishing.

Wittwer, J., & Renkl, A. (2010). How effective are instructional explanations in example-based learning? A meta-analytic review. *Educational Psychology Review*, 22(4), 393-409.

Woodward, J., Beckmann, S., & Driscoll, M. (2012). Improving mathematical problem solving in grades 4 through 8: A practice guide (NCEE 2012-4055). Washington, DC: National Center for Education Evaluation and Regional Assistance, Institute of Education Sciences,

U.S. Department of Education. Retrieved from http://ies.ed.gov/ncee/wwc/publications_reviews.aspx#pubsearch/
Zachtronics. (2014). MetaboSIM. *Retrieved from http://www.zachtronics.com/metabosim/.*
Zandberg, I., & Lewis, L. (2008). Technology-Based Distance Education Courses for Public Elementary and Secondary School Students: 2002-03 and 2004-05. Statistical Analysis Report. NCES 2008-008. *National Center for Education Statistics*.
Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In Boekaerts, M., Pintrich, P.R., & Zeidner, M. (Eds.), *Handbook of Self-Regulation* (pp. 13-35). London: Academic Press.