Mystery Science

Theory of Action References

Mystery Science is built upon a theory of action about how best to enhance K-5 science instruction and the learning experience. A theory of action is a collection of statements that hypothesize how intentional actions will result in change, based on insights from existing research. Collectively, our theory of action statements describes the philosophical foundation underpinning our approach to science education. This document includes research to support the following Theory of Action statements:

Students

1. When students construct their knowledge through active application of science practices, they deepen their understanding of scientific concepts.

2. When students see how scientific ideas relate to their daily lives and personal interests, they are more motivated and engaged in learning.

3. When students analyze scientific ideas through the lens of phenomena, they are able to solve real-world problems.
4. When students feel welcome and included through conceptual and linguistic accessibility and learn from content that is diverse in representation, they are more engaged in learning.

Teachers

5. When teachers provide appropriately scaffolded instruction, students are more likely to grow their understanding of scientific concepts.

6. When teachers relate lessons to prior knowledge, students are more likely to engage in the lesson and achieve the intended learning goals.

7. When lessons include expectations that students apply scientific practices (e.g. solve problems, engage in argumentation, analyze data, develop and use models), students are more engaged, and deeper understanding and active learning takes place.

8. When lessons include frequent opportunities for scientific discourse (e.g., sharing ideas during the investigation, making predictions, arguing for ideas using evidence, synthesizing findings), teachers can support students in developing and deepening their understanding of scientific ideas.

Administrators

9. When district and school-based leaders invest in, prioritize, and support the use of research-based, digital learning resources by teachers and students, engagement and achievement increases.

10. When administrators prioritize science education by providing effective professional development, high-quality curricular resources, and ample instructional time, students are more likely to engage in science and achieve the intended learning goals.

11. When district and school-based leaders invest in digital resources that are intuitive for users, teachers are more likely to use them for teaching and learning.

The studies and papers listed under each theory of action statement provide guidance to our product development and product design, professional learning and partner success teams when creating, developing, and implementing our program. Relevant excerpts from the abstracts, summaries of findings and recommendations are included verbatim unless otherwise noted.

Theory of Action Statement 1

When students construct their knowledge through active application of science practices, they deepen their understanding of scientific concepts.

1. Developing 21st Century Skills through a Constructivist-Constructionist Learning Environment

Ah-Nam, L. & Osman, K. (2017). Developing 21st Century Skills through a Constructivist-Constructionist Learning Environment. K-12 STEM Education, 3(2), 205-216. The Institute for the Promotion of Teaching Science and Technology (IPST). Retrieved June 23, 2023, from https://www.learntechlib.org/p/209542/

Science and technology innovation and 21st century skills are increasingly important in the 21st century workplace. The purpose of this study is to propose an instructional strategy that develop constructivist-constructionist learning environment that simultaneously develop chemistry knowledge and 21st century skills. Based on constructivist and constructionist learning theories, we identified three central guiding principles for this study: (1) engage students in discovery and problem-solving task through teamwork, (2) provide opportunities for communicating ideas, and (3) involve students in the process of design. An intervention module, Malaysian Kimia (chemistry) Digital Game known as MyKimDG, was developed as a mechanism for creating the learning environment. In this study, students were required to work collaboratively to design educational media that help their peers who face difficulty in learning particular concept. They were guided to go through the IDPCR (Inquiry, Discover, Produce, Communicate and Review) phases. It is hypothesized that MyKimDG can create learning environment that allows students to deepen subject content knowledge and practice various 21st century skills in real situation. This study employed quasi-experimental study with non-equivalent control group pretest-posttest control group design. Results suggest that this approach is able to improve the acquisition of chemistry knowledge and high productivity skill.

2. Modern Scientific Literacy: A Case Study of Multiliteracies and Scientific Practices in a Fifth Grade Classroom

Allison, E., & Goldston, M. J. (2018). Modern scientific literacy: A case study of multiliteracies and scientific practices in a fifth-grade classroom. Journal of Science Education and Technology, 27(3), 270-283. URL

This study investigates the convergence of multiliteracies and scientific practices in a fifth-grade classroom. As students' lives become increasingly multimodal, diverse, and globalized, the traditional notions of literacy must be revisited (New London Group 1996). With the adoption of the Next Generation Science Standards (NGSS Lead States 2013a) in many states, either in their entirety or in adapted forms, it becomes useful to explore the interconnectedness multiliteracies and scientific practices and the resulting implications for scientific literacy. The case study included a fifth-grade classroom, including the students and teacher. In order to create a rich description of the cases involved, data were collected and triangulated through teacher interviews, student interviews and focus groups, and classroom observations. Findings reveal that as science activities were enriched with multiliteracies and scientific practices, students were engaged in developing skills and knowledge central to being scientifically literate. Furthermore, this study establishes that characteristics of scientific literacy, by its intent and purpose, are a form of multiliteracies in elementary classrooms. Therefore, the teaching and learning of science and its practices for scientific literacy are in turn reinforcing the development of broader multiliteracies.

3. The Effect of Constructivist Learning Approach and Active Learning on Environmental Education: A Meta-Analysis Study

Arik, S., & Yilmaz, M. (2020). The effect of constructivist learning approach and active learning on environmental education: a meta-analysis study. *International Electronic Journal of Environmental Education*, *10*(2), 44-84.

This study conducted a meta-analysis of 57 primary experimental studies which involved 6237 students and investigated the effect of constructivist learning approach and active learning on students' environmental education. The study also analyzed a set of moderator variables, which are considered to influence the results of the primary studies in line with the findings of the meta-analysis. The moderator variables included "year of publication", "language of publication", "type of publication", "country", "educational level", "sample size", "type of measuring instrument in terms of questions and developer", "duration of experimental intervention", "research design", "teacher and researcher effect", and "type of constructivist learning approach and active learning method". The sample consisted of 6237 students and 57 primary experimental studies on environmental academic achievement and environmental attitudes, which were conducted between 2000 and 2015 and met the inclusion and exclusion criteria. A total of 114 effect sizes were obtained from 57 studies. This study used a meta-analysis approach, which is a retrospective study design. The data were analyzed using meta-analysis. The meta-analysis of the data was performed using a random- effects statistical model. Hedges' g was used to measure effect size. Moderator variables were analyzed using the analog to the analysis of variance (ANOVA) based on random-effects and mixed-effects models. The results of the meta-analysis showed that the overall effect size of constructivist learning approach and active learning on environmental education compared to traditional learning is positive and large (Hedges' g= 1.463). According to the results of the moderator analysis, constructivist learning-based and active learning-based environmental education significantly differed in terms of "country", "sample size", "educational level", "type of publication", "type of measuring instrument", "developer of measuring instrument", "language of publication", "teacher effect", and "researcher effect". On the other hand, no significant difference was found in terms of "year of publication", "duration of experimental intervention", "research design", and "type of teaching method used in the experimental group". Taken together, these findings suggest that constructivist learning, and active learning can often be used in environmental education. The following variables should be considered in environmental education practices: sample size of the experimental group, educational level of students, measuring instruments employed, and researchers conducting the experiment, and duration of experimental intervention.

4. Teaching Science as Practice

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (2007). Teaching science as practice. In Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.), Taking science to school: Learning and teaching science in grades K-8. National Academies Press. URL

In this chapter we focus on the classroom-level implications of the learning and instruction research. The chapter is divided into four sections. First, we begin with a description of typical instruction in U.S. K-8 science classrooms. In the second section we present the contrasting view of science as practice put forth in the instructional research, pointing to promising evidence of student learning when instruction is framed around science as practice. In the third section we look more closely at the common forms of scientific practice that students engage in across different types of instructional design, pointing to the challenges students encounter as they do so. Fourth, we characterize strategies that teachers and curriculum developers can use to promote student learning of science through practice. We close with the major conclusions that can be drawn from current research on science instruction.

5. Comparing Two Approaches to Engineering Design in the 7th Grade Science Classroom

Goldstein, M. H., Omar, S. A., Purzer, S., & Adams, R. S. (2018). Comparing two approaches to engineering design in the 7th grade science classroom. International Journal of Education in Mathematics, Science and Technology, 6(4), 381-397. URL

This study compares two design projects implemented in 7th grade classrooms (n=677) at two different schools to explain affordances of each approach based on differences in project authenticity, scale, and depth of context in supporting student learning outcomes. The main data sources were an engineering science test and a design reasoning elicitation problem, administered at each school before and after the design project. To understand the relationship between students' science learning gains and school implementation, we conducted a sign test to compare between-group differences and a Mann Whitney Test to compare within-group differences. Then, we performed a content

analysis to examine students' design reasoning and a two-way contingency table analysis to understand if a student's school implementation was related to the changes in design trade-off reasoning. Students at both schools exhibited statistically significant but small gains on their engineering science test scores. While students at the school with a more interdisciplinary, more authentic design project had higher scores on the engineering science test, students at the school with a smaller scale implementation discussed more trade-off factors in their design reasoning elicitation problem. These findings suggest that differences in project implementation appear to be associated with different learning outcomes, and there are potential benefits to both authenticity and simplicity in design projects.

6. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. The National Academies Press. URL

Science, engineering, and technology permeate nearly every facet of modern life and hold the key to solving many of humanity's most pressing current and future challenges. The United States' position in the global economy is declining, in part because U.S. workers lack fundamental knowledge in these fields. To address the critical issues of U.S. competitiveness and to better prepare the workforce, *A Framework for K-12 Science Education* proposes a new approach to K-12 science education that will capture students' interest and provide them with the necessary foundational knowledge in the field.

7. Using Technology-Enhanced Inquiry-Based Instruction to Foster the Development of Elementary Students' Views on the Nature of Science

Schellinger, J., Mendenhall, A., Alemanne, N., Southerland, S. A., Sampson, V., & Marty, P. (2019). Using technology-enhanced inquiry-based instruction to foster the development of elementary students' views on the nature of science. Journal of Science Education and Technology, 28(4), 341-352. URL

The Next Generation Science Standards support understanding of the nature of science as it is practiced and experienced in the real world through interconnected concepts to be imbedded within scientific practices and crosscutting concepts. This study explored how fourth and fifth grade elementary students' views of nature of science change when they engage in a technology-enhanced, scientific inquiry-oriented curriculum that takes place across formal and informal settings. Results suggest that student engagement in technology-enhanced inquiry activities that occur in informal and formal settings when supported through explicit instruction focused on metacognitive and social knowledge construction can improve elementary students' understanding of nature of science.

8. Positioning Participation in the NGSS Era: What Counts as Success?

Zangori, L., & Pinnow, R. J. (2020). Positioning participation in the NGSS era: What counts as success? Journal of Research in Science Teaching, 57(4), 623-648. URL

The Next Generation Science Standards (NGSS) strives to shift science learning from the teacher as a single cognitive agent, to a classroom community in which participants are working together in directing the classroom's communal knowledge to figure out questions about how phenomena occur, and building, testing, and refining their ideas to address those questions. To achieve this type of classroom environment, teachers should attend to students' knowledge and ideas and pay attention to how students are located within teacher-led interactions, such as being positioned as active discussants or designated listeners. In this study, we explore if and how this is occurring in the NGSS era. We used a naturalistic inquiry to explore how an experienced first-grade teacher used a new NGSS-aligned unit that called for students to use the science and engineering practices (SEP) to build content knowledge. We used a macro-analytic lens to answer the research question "how are class discussions shaped to address the SEP"? We used a micro-analytic lens to answer the research question "how are students positioned during these science discussions in this classroom?" Evidence suggests that the teachers' whole class discussions incorporated and involved the SEP which were specified in the unit lessons for content learning. However, on a micro-analytic level, we found that few students were positioned as active discussants. The teacher heavily relied on those students who could provide succinct and clearly relevant answers while positioning the remainder of the students as

silent spectators. Implications from this research suggest that not only new NGSS curriculum materials need to focus on what students should know and do but they also need to address heuristics for teachers that show them how to position all of their students as active doers of science, so all students have opportunities to build deeper, core science knowledge.

Theory of Action Statement 2

When students see how scientific ideas relate to their daily lives and personal interests, they are more motivated and engaged in learning.

1. Promoting Interest and Performance in High School Science Classes

Hulleman, C. S., & Harackiewicz, J. M. (2009). Promoting interest and performance in high school science classes. science, 326(5958), 1410-1412. URL

We tested whether classroom activities that encourage students to connect course materials to their lives will increase student motivation and learning. We hypothesized that this effect will be stronger for students who have low expectations of success. In a randomized field experiment with high school students, we found that a relevance intervention, which encouraged students to make connections between their lives and what they were learning in their science courses, increased interest in science and course grades for students with low success expectations. The results have implications for the development of science curricula and theories of motivation.

2. The Influence of Inquiry-Based Teaching on Male and Female Students' Motivation and Engagement

Kuo, Y. R., Tuan, H. L., & Chin, C. C. (2020). The influence of inquiry-based teaching on male and female students' motivation and engagement. Research in Science Education, 50(2), 549-572. URL

This study aims to examine the influence of inquiry-based instruction on eighth-grade male and female students' motivation and engagement in science learning in two public junior high schools in central Taiwan. Mixed-methods methodology was adopted with 60 students (32 males and 28 females) in the experimental group and 56 students (28 males and 28 females) in the control group. The study lasted for one semester and six units using inquiry-based teaching (90–180 min each) were implemented in the experimental group. Questionnaires used for measuring students' motivation and engagement in science learning were administered as pre- and post-tests. In addition, eight to ten male and female students from both experimental and control groups, as well as two instructors were interviewed four times throughout the semester. Quantitative data were analyzed with t test and the interview data were fully transcribed and coded. Results show that male and female students under intervention expected to do more experiments because it improved their understanding. Male and female students under intervention also used more learning strategies. However, males benefited more than females from the intervention in regard to their motivation and engagement in learning science. Males improved more in motivational constructs, recognized the value of learning science, and increased their cognitive, behavioral, and emotional engagement because what they learned applied to real life. In contrast, females had higher exam anxiety and lower cognitive engagement due to mathematics fear, stronger sense of pride in class, and caring too much about the right answers.

3. Storyline Units: An Instructional Model to Support Coherence from the Students' Perspective.

Reiser, B. J., Novak, M., McGill, T. A., & Penuel, W. R. (2021). Storyline units: An instructional model to support coherence from the students' perspective. Journal of Science Teacher Education, 32(7), 805-829. URL

The vision of the Framework and NGSS requires important shifts in teaching approaches and instructional materials. We argue that this commitment to engaging learners in meaningful practice and supporting students' epistemic agency entails that we support coherence from the students' perspective. This coherence arises when students see their science work as making progress on questions and problems their classroom community has committed to address, rather than simply following directions from textbooks or teachers. We present an instructional model, storylines, to

support this form of coherence. The storylines approach includes design principles for engaging students with phenomena and problems to elicit their own questions that teachers, with support of curriculum materials, use to guide the trajectory of their sensemaking. We describe how storylines organize cycles of engaging with phenomena, questions, and sensemaking to incrementally build, test, and revise explanatory models and design solutions. Storylines are supported by a collection of instructional routines and norms that provide strategies and tools to guide teachers' work with students around phenomena, questions, and sensemaking. The routines reflect strategies for eliciting questions from anchoring phenomena, navigation to engage students as partners in managing the direction of investigations, problematizing to help students find gaps in their work so far, and putting pieces together to support students in assembling what they have figured out. We present examples from elementary, middle, and high school storyline-based units awarded the NGSS design badge to illustrate the application of these design principles in the design and enactment of storyline-based units.

4. Teaching Urban High School Students Global Climate Change Information and Graph Interpretation Skills Using Evidence from the Scientific Literature

Rule, A. C., & Meyer, M. A. (2009). Teaching urban high school students global climate change information and graph interpretation skills using evidence from the scientific literature. Journal of Geoscience Education, 57(5), 335-347. URL

Curriculum materials designed to provide students with practice interpreting plotted evidence of global climate change were developed using graphs from the scientific literature and tested with one hundred urban high school students from a high-poverty school in a major northern city in the US. The graph interpretation lessons followed a constructivist-teaching learning cycle format. Additional activities included watching videos related to climate change and completing a graphing exercise. Students displayed motivation during the lessons along with significant improvement from pretest to posttest in graph interpretation skills and content knowledge of organisms affected by climate change. Student motivation was revealed by task commitment during the exercises as well as requests for additional activities related to investigating environmental effects on organisms and stopping global climate change. The efficacy of the lessons is attributed to the concrete, manipulative nature of the graph interpretation sets, real-world connections of the topic, the focus on interesting organisms, the opportunity for students to express their views, and the use of multi-media.

5. Contemporary Science Practice in the Classroom: A Phenomenological Exploration into How Online Curriculum Resources Can Facilitate Learning

Vamvakas, M., White, P., & Tytler, R. (2021). Contemporary science practice in the classroom: A phenomenological exploration into how online curriculum resources can facilitate learning. International Journal of Science Education, 43(13), 2087-2107. URL

Using a phenomenological lens, we investigated how online curriculum resources can support secondary science teachers to explore contemporary science practices with their students. The research used a social constructivist theoretical and a hermeneutic phenomenology methodological framework to describe and interpret the teacher/participants' experience. Seven participants teaching science to Year 7-10 students (12-15 years old) engaged in the research project, trialing selected contemporary science resources in their class. Pre and post intervention interviews were conducted with each participant along with classroom observations of one lesson to view aspects of the effectiveness of the resource, the teachers' approach and their perceptions of student learning and engagement. Discussion focuses on how the online curriculum resources presented alternative views about science in practice to what students expect, providing an in-depth view of scientists and their research practices in varied settings. Affordances of this approach for bringing real science into the classroom and for improving student engagement and learning are considered. The findings point to the approach being potentially a productive, scalable way forward for introducing contemporary science practice into classrooms. We advocate further research investigating the potential of this type of online curriculum resource to connect students more powerfully with scientists and their practices.

Theory of Action Statement 3

When students analyze scientific ideas through the lens of phenomena, they are able to solve real-world problems.

1. A Case Study of Project-Based Instruction in the Ninth Grade: A Semester-Long Study of Intertidal Biodiversity

Baumgartner, E. and Zabin, C. J. (2008). A case study of project-based instruction in the ninth grade: A semester-long study of intertidal biodiversity. Environmental Education Research, 14(2), 97-114. URL

In this descriptive case study, project-based learning is presented as a teaching model that combines elements from other learning strategies. High school students participating in an intertidal monitoring project built around this model increased their content knowledge related to the ecology of the intertidal zone and improved their scientific investigation skills. Several aspects of project-based instruction are considered critical to success. Projects grounded in authentic scientific research develop scientific investigation skills through real world application. Alignment of scientific and educational goals enhances learning when the project is conducted in a sound pedagogical manner while maintaining scientific authenticity. Student teamwork builds a scientific community and makes the work more manageable. One of the most critical elements for success is a long-term commitment to project activities with connections between the project and related curricular topics. Flexibility of the school curriculum enables required content to be connected to the project's thematic base. These connections provide students with a common knowledge foundation and make it easier for educators to build such projects into their curricula.

2. Fostering Student Engagement Through a Real-world, Collaborative Project across Disciplines and Institutions

Mebert, L., Barnes, R., Dalley, J., Gawarecki, L., Ghazi-Nezami, F., Shafer, G., Slater, J., & Yezbick, E. (2020). Fostering student engagement through a real-world, collaborative project across disciplines and institutions. Higher Education Pedagogies, 5(1), 30-51. URL

Ample research has identified several features of a learning experience likely to enhance student learning, including collaboration, open-ended exploration, and problem-based learning in real-life scenarios. Missing is a model of how instructors might combine these elements into a single project that works flexibly across disciplines and institutions. This article fills this gap by offering such a model and reporting on its effectiveness in fostering student engagement. It describes a project that instructors at four colleges and universities in Flint, Michigan (USA) piloted during the height of the Flint water crisis. The project asked students to apply class content to the real-world problem unfolding around them and offered students an opportunity to collaborate with peers. We collected qualitative and quantitative data on students' reactions to the project and found that the project succeeded in engaging students. We offer recommendations for how instructors can create similar projects in their own classrooms.

3. Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices

Schwarz, C. V., Passmore, C., & Reiser, B. J. (2017). Helping students make sense of the world using next generation science and engineering practices. NSTA Press. URL

When it's time for a game change, you need a guide to the new rules. Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices provides a play-by-play understanding of the practices strand of A Framework for K–12 Science Education (Framework) and the Next Generation Science Standards (NGSS). Written in clear, nontechnical language, this book

provides a wealth of real-world examples to show you what's different about practice-centered teaching and learning at all grade levels. The book addresses three important questions:

1. How will engaging students in science and engineering practices help improve science education?
2. What do the eight practices look like in the classroom?
3. How can educators engage students in practices to bring the NGSS to life?

Helping Students Make Sense of the World Using Next Generation Science and Engineering Practices was developed for K–12 science teachers, curriculum developers, teacher educators, and administrators. Many of its authors contributed to the Framework's initial vision and tested their ideas in actual science classrooms. If you want a fresh game plan to help students work together to generate and revise knowledge—not just receive and repeat information—this book is for you.

4. Engaged and Learning Science: How Students Benefit from Next Generation Science Standards Teaching

Tyler, B., Britton, T., Iveland, A., Nguyen, K., & Hipps, J. (2018). Engaged and learning science: How students benefit from Next Generation Science Standards teaching. WestEd. URL

The Next Generation Science Standards (NGSS) impact students in substantive ways. These standards move beyond textbooks to emphasize hands-on inquiry focused on real-world phenomena -- making students, rather than teachers, the primary actors in the NGSS science classroom. The six-year NGSS Early Implementers Initiative has supported a group of California school districts in implementing the NGSS. This evaluation report -- intended for school, state, and district leaders -- describes how a diverse population of students are benefiting from their districts' participation in this Initiative. The evaluation's findings show that these diverse students are: (1) More excited about and engaged in science; (2) Experiencing more inclusive participation; and (3) Showing evidence of higher-level learning. The report discusses the results of whole-class surveys administered to students in the K-2, 3-5, and 6-8 grade spans, which suggest that not only are the Initiative's Teacher Leaders providing teaching aligned to the NGSS, but they are also fostering student confidence and promoting stronger interest in science. The report also presents an extended vignette of a 4th grade lesson to illustrate the student experiences and benefits that occur in NGSS instruction. The conclusion of the report provides recommendations for administrators to support their teachers in enhancing student engagement and learning.

5. Contemporary Science Practice in the Classroom: A Phenomenological Exploration into How Online Curriculum Resources Can Facilitate Learning

Vamvakas, M., White, P., & Tytler, R. (2021). Contemporary science practice in the classroom: A phenomenological exploration into how online curriculum resources can facilitate learning. International Journal of Science Education, 43(13), 2087-2107. URL

Using a phenomenological lens, we investigated how online curriculum resources can support secondary science teachers to explore contemporary science practices with their students. The research used a social constructivist theoretical and a hermeneutic phenomenology methodological framework to describe and interpret the teacher/participants' experience. Seven participants teaching science to Year 7-10 students (12-15 years old) engaged in the research project, trialing selected contemporary science resources in their class. Pre and post intervention interviews were conducted with each participant along with classroom observations of one lesson to view aspects of the effectiveness of the resource, the teachers' approach and their perceptions of student learning and engagement. Discussion focuses on how the online curriculum resources presented alternative views about science in practice to what students expect, providing an in-depth view of scientists and their research practices in varied settings. Affordances of this approach for bringing real science into the classroom and for improving student engagement and learning are considered. The findings point to the approach being potentially a productive, scalable way forward for introducing contemporary science practice into classrooms. We advocate further research investigating the potential of this type of online curriculum resource to connect students more powerfully with scientists and their practices.

Theory of Action Statement 4

When students feel welcome and included through conceptual and linguistic accessibility and learn from content that is diverse in representation, they are more engaged in learning.

1. Examining Classroom Contexts in Support of Culturally Diverse Learners' Engagement: An Integration of Self-Regulated Learning and Culturally Responsive Pedagogical Practices

Anyichie, A. C., Butler, D. L., Perry, N. E., & Nashon, S. M. (2023). Examining Classroom Contexts in Support of Culturally Diverse Learners' Engagement: An Integration of Self-Regulated Learning and Culturally Responsive Pedagogical Practices. *Frontline Learning Research*, *11*(1), 1–39. https://doi.org/10.14786/flr.v11i1.1115

Research shows that culturally diverse students are often disengaged in multicultural classrooms. To address this challenge, literatures on self-regulated learning (SRL) and culturally responsive teaching (CRT) both document practices that foster engagement, although from different perspectives. This study examined how classroom teachers at schools that enroll students from diverse cultural communities on the West Coast of Canada built on a Culturally Responsive Self-Regulated Learning Framework to design complex tasks that integrated SRL pedagogical practices (SLPPs) and culturally responsive pedagogical practices (CRPPs) to support student engagement. Two elementary school teachers and their 43 students (i.e., grades 4 and 5) participated in this study. We used a multiple, parallel case study design that embedded mixed methods approaches to examine how the teachers integrated SRLPPs and CRPPs into complex tasks; how culturally diverse students engaged in each teacher's task; and how students' experiences of engagement were related to their teachers' practices. We generated evidence through video-taped classroom observations, records of classroom practices, students' work samples, a student self-report, and teacher interviews. Overall findings showed: (1) that teachers were able to build on the CR-SRL framework to guide their design of an CR-SRL complex task; (2) benefits to students' engagement when those practices were present; and (3) dynamic learner-context interactions in that student engagement were situated in features of the complex task that were present on a given day. We close by highlighting implications of these findings, limitations, and future directions.

2. The Theory and Practice of Culturally Relevant Education: A Synthesis of Research Across Content Areas

Aronson, B., & Laughter, J. (2016). The theory and practice of culturally relevant education: A synthesis of research across content areas. Review of Educational Research, 86(1), 163-206.

Many teachers and educational researchers have claimed to adopt tenets of culturally relevant education (CRE). However, recent work describes how standardized curricula and testing have marginalized CRE in educational reform discourses. In this synthesis of research, we sought examples of research connecting CRE to positive student outcomes across content areas. It is our hope that this synthesis will be a reference useful to educational researchers, parents, teachers, and education leaders wanting to reframe public debates in education away from neoliberal individualism, whether in a specific content classroom or in a broader educational community.

3. A Meta synthesis of the Complementarity of Culturally Responsive and Inquiry-based Science Education in K-12 Settings: Implications for Advancing Equitable Science Teaching and Learning

Brown, J. C. (2017). A meta synthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. Journal of Research in Science Teaching, 54(9), 1143-1173.

Employing meta synthesis as a method, this study examined 52 empirical articles on culturally relevant and responsive science education in K-12 settings to determine the nature and scope of complementarity between culturally responsive and inquiry-based science practices (i.e., science and engineering practices identified in the National Research Council's *Framework for K-12 Science*

Education). The findings from this study indicate several areas of complementarity. Most often, the inquiry-based practices *Obtaining, Evaluating, and Communicating Information, Constructing Explanations and Designing Solutions*, and *Developing and Using Models* were used to advance culturally responsive instruction and assessment. The use and development of models, in particular, allowed students to explore scientific concepts through families' funds of knowledge and explain content from Western science and Indigenous Knowledge perspectives. Moreover, students frequently *Analyzed and Interpreted Data* when interrogating science content in sociopolitical consciousness-raising experiences, such as identifying pollution and asthma incidences in an urban area according to neighborhood location. Specific inquiry-based practices were underutilized when advancing culturally responsive science instruction, though. For example, *Using Mathematics and Computational Thinking* and *Engaging in Argument from Evidence* were infrequently encountered. However, culturally responsive engineering-related practices were most often connected with these, and thus, represent potential areas for future complementarity, particularly as the United States embraces the Next Generation Science Standards. In considering innovative directions for advancing equitable science education, several possibilities are discussed in light of the findings of this study.

4. Promoting Student Engagement in the Classroom

Bundick, M. J., Quaglia, R. J., Corso, M. J., & Haywood, D. E. (2014). Promoting student engagement in the classroom. Teachers College Record, 116(4).

Background/Context: Much progress has been made toward a greater understanding of student engagement and its role in promoting a host of desirable outcomes, including academic outcomes such as higher achievement and reduced dropout, as well as various well-being and life outcomes. Nonetheless, disengagement in our schools is widespread. This may be due in part to a lack in the student engagement literature of a broad conceptual framework for understanding how students are engaged at the classroom level, and the ways in which teachers may play an active role in promoting student engagement. Purpose: The present work seeks to summarize and synthesize the literature on student engagement, providing both a greater appreciation of its importance as well as a context for how it might be better understood at the classroom level. It considers how the primary elements of the classroom environment—the student, the teacher, and the content—interact to affect engagement, and proposes a conceptual framework (based on a previously established model of classroom instruction and learning) for understanding how student engagement may be promoted in the classroom. Research Design: This study combines a review of the extant research on the structure and correlates of student engagement, with elements of an analytic essay addressing how selected literature on motivation and classroom instruction may be brought to bear on the understanding and promotion of student engagement in the classroom. Conclusions/Recommendations: This article offers a variety of research-based practical suggestions for how the proposed conceptual model—which focuses on student–teacher relationships, the relevance of the content to the students, and teachers' pedagogical and curricular competence—might be applied in classroom settings.

5. Does Culturally Relevant Teaching Work? An Examination from Student Perspectives

Byrd, C. M. (2016). Does culturally relevant teaching work? An examination from student perspectives. Sage Open, 6(3), 2158244016660744.

Culturally relevant teaching is proposed as a powerful method for increasing student achievement and engagement and for reducing achievement gaps. Nevertheless, the research demonstrating its effectiveness consists primarily of case studies of exemplary classrooms. In addition, most of the research fails to take student perspectives into account. The current study asks whether culturally relevant teaching works by considering student perceptions of classrooms that vary in the amount of culturally relevant practices. The sample was 315 sixth- through 12th-grade students sampled from across the United States (62% female, 25% White, 25% Latino, 25% African American, and 25% Asian) who completed surveys of their experiences of culturally relevant teaching, cultural socialization, opportunities to learn about other cultures, and opportunities to learn about racism. Elements of culturally relevant teaching were significantly associated with academic outcomes and

ethnic racial identity development. The findings provide support for the effectiveness of culturally relevant teaching in everyday classrooms.

6. Culturally Responsive Teaching Principles, Practices, and Effects

Gay, G. (2013). Culturally responsive teaching principles, practices, and effects. In Handbook of urban education (pp. 391-410). Routledge.

Persistent achievement disparities among students and enrollment patterns in urban schools demand serious consideration of culturally responsive teaching. Minimally, this consideration should examine why it is important to incorporate the cultural heritages, experiences, and perspectives of ethnically diverse students into educational programs and practices designed for them, how this can be accomplished in practice, and what consequences it generates. This discussion addresses these issues. It begins with a brief overview of the urban education context and why culturally responsive teaching is a good fi t for it. This is followed by a summary of major assumptions, attributes, and principles of culturally responsive teaching. Third, some samples of culturally responsive programs and practices are examined. They target a variety of ethnic student populations, including African Americans, Asian/Pacific Islanders, Latino Americans, Native Americans, and Native Alaskans, and different levels of schooling (elementary, secondary, and college). In addition to describing the features of these practices, the results they accomplish in improving student achievement are presented. These achievements are academic, social, cultural, and personal.

7. Culturally Responsive Teaching: Theory, Research, and Practice

Gay, G. (2018). Culturally responsive teaching: Theory, research, and practice. Teachers College Press.

Geneva Gay is renowned for her contributions to multicultural education, particularly as it relates to curriculum design, ‘professional learning’, and classroom instruction. Gay has made many important revisions to keep her foundational, award-winning text relevant for today’s diverse student population, including new research on culturally responsive teaching, a focus on a broader range of racial and ethnic groups, and consideration of additional issues related to early childhood education. Combining insights from multicultural education theory with real-life classroom stories, this book demonstrates that all students will perform better on multiple measures of achievement when teaching is filtered through students’ own cultural experiences.

8. Culturally Responsive Teaching and the Brain: Promoting Authentic Engagement and Rigor Among Culturally and Linguistically Diverse Students

Hammond, Z. (2014). Culturally responsive teaching and the brain: Promoting authentic engagement and rigor among culturally and linguistically diverse students. Corwin Press.

To close the achievement gap, diverse classrooms need a proven framework for optimizing student engagement. Culturally responsive instruction has shown promise, but many teachers have struggled with its implementation—until now. In this book, Zaretta Hammond draws on cutting-edge neuroscience research to offer an innovative approach for designing and implementing brain-compatible culturally responsive instruction. The book includes:

- Information on how one’s culture programs the brain to process data and affects learning relationships
- Ten “key moves” to build students’ learner operating systems and prepare them to become independent learners
- Prompts for action and valuable self-reflection

9. Developing Instructional Materials Aligned to the Next Generation Science Standards for All Students, Including English Learners

Haas, A., Januszyk, R., Grapin, S. E., Goggins, M., Llosa, L., & Lee, O. (2021). Developing instructional materials aligned to the next generation science standards for all students, including English learners. Journal of Science Teacher Education, 32(7), 735-756.

The adoption of *A Framework for K-12 Science Education* and the Next Generation Science Standards (NGSS) across the U.S. requires that the field of science education develops high-quality

instructional materials. This need is particularly urgent as schools and districts are expected to design or adapt instructional materials for an increasingly diverse student population. In this article, we present our conceptual approach for developing yearlong fifth grade NGSS-aligned instructional materials with a focus on English learners. First, we describe the conceptual framework focused on equity that guided our development work. Second, we describe our design-based research with teachers and our instructional materials development process that leveraged the synergy of the NGSS performance expectations (PEs), phenomena, and students. Specifically, we address equity in our materials in two ways: (a) selection of local phenomena rooted in students' homes and communities and (b) attention to language use in terms of modalities, registers, and interactions. Third, we illustrate our development process using an exemplar unit from our curriculum. Finally, we discuss implications for instructional materials development, including how we productively resolved tensions in developing our materials and how we both benefited from teachers' participation in the development process and promoted their professional learning.

10. Driving Equity in Action Through a Socially and Culturally Situated Pedagogy: Culturally Relevant Teaching and Learning as a Form of Equity Toward Student Engagement

Lalas, J. W., & Strikwerda, H. L. (2020). Driving equity in action through a socially and culturally situated pedagogy: Culturally relevant teaching and learning as a form of equity toward student engagement. In Overcoming current challenges in the P-12 teaching profession (pp. 291-315). IGI Global.

Culturally relevant teaching and learning is a good approach for complementing equity work, but educators are not particularly familiar with it and intentionally employing it in schools although the concept of culturally relevant pedagogy or CRP has been introduced to the professional literature for more than 20 years ago. It is vital that educators understand the role of culturally relevant teaching and learning in supporting equity as a remedy for eliciting more active and productive student engagement. All educators involved in promoting and implementing equity as a solution toward student engagement and achievement must accept the reality that it needs not only understanding of what educational practice works and does not work but also patience and realistic expectation that equity's challenging work is an on-going and long-lasting advocacy. As educators who are social justice advocates, we must reimagine teaching and learning as a socially and culturally situated pedagogy to increase motivation, engagement, and hope to meet the needs of all our students, when they need them.

11. English Learners in STEM Subjects: Transforming Classrooms, Schools, and Lives

National Academies of Sciences, Engineering, and Medicine. 2018. English Learners in STEM Subjects: Transforming Classrooms, Schools, and Lives. Washington, DC: The National Academies Press. doi: 10.17226/25182.

English Learners in STEM Subjects: Transforming Classrooms, Schools, and Lives examines the research on ELs' learning, teaching, and assessment in STEM subjects and provides guidance on how to improve learning outcomes in STEM for these students. This report considers the complex social and academic use of language delineated in the new mathematics and science standards, the diversity of the population of ELs, and the integration of English as a second language instruction with core instructional programs in STEM.

Theory of Action Statement 5

When teachers provide appropriately scaffolded instruction, students are more likely to grow their understanding of scientific concepts.

1. Instructional Scaffolding in STEM Education: Strategies and Efficacy Evidence
Belland, B. R. (2017). *Instructional scaffolding in STEM education: Strategies and efficacy evidence* (p. 144). Springer Nature.

This book explores the use of problem-centered instructional approaches in STEM education. The author explains the theoretical background of scaffolding, explores the theoretical implications of a meta-analysis, posits instructional scaffolding as an intervention that extends students' capabilities as they engage with the central problem in problem-centered instructional approaches, and synthesizes relevant research. The author concludes that computer-based scaffolding is a highly effective intervention that leads to strong effect sizes that are statistically significant across contexts of use, intended learning outcomes, and scaffolding characteristics. It can do this by extending students' abilities in the following areas: argumentation, modeling, problem-solving, and forming coherent mental models to describe natural phenomena. As such, computer-based scaffolding is a timely intervention that raises the likelihood that problem-centered models will be successful. Research outlined in this book can contribute to an understanding of the scaffolding goals, strategies, and contexts of use that are associated with the strongest cognitive learning outcomes.

2. Beyond the Controversy: Instructional Scaffolds to Promote Critical Evaluation and Understanding in Earth Science
Lombardi, D. (2016). Beyond the controversy: instructional scaffolds to promote critical evaluation and understanding in earth science. *The Earth Scientist*, *32*(2), 5-10.

The Model-Evidence Link (MEL) diagram activities are scaffolds that facilitate students' weighing and coordinating of the connection between evidence and models. MELs help students learn about fundamental Earth and space science content that underlies socio-scientific, complex, and abstract issues. Our project team has been developing and testing four MELs about socio-scientific issues (climate change, wetlands and land use, fracking and earthquakes) and abstract ideas (formation of Earth's Moon) for use in high school classrooms. These MEL activities facilitate students' critical evaluations of alternatives, which is a skill necessary to engage in many scientific and engineering practices. Being critically evaluative allows students to go beyond the controversy and reason scientifically through coordination of evidence and models.

3. Developing a Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners
Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 46(6), 632-654. URL

Students were able to construct models that were abstracted to some extent from the specifics of the phenomena they studied and captured important explanatory mechanisms and relationships between the components (e.g., water particles moving from liquid to gas, odor particles in motion, colliding with air particles). Students were able to use models to make predictions about closely related phenomena, drawing directly on the explanations captured in the models to make predictions for a new situation. They were able to evaluate and compare models and determine which aspects to include in a consensus model. Finally, they were able to revise their models when learning more about the phenomena, and constructed multiple models that successively increased in sophistication. Furthermore, there is initial evidence that students were developing some aspects of the important understandings about this practice.

4. Scaffolding Disciplined Inquiry in Problem-based Environments

Simons, K. D., & Ertmer, P. A. (2005). Scaffolding disciplined inquiry in problem-based environments. *International Journal of Learning*, *12*(6), 297-305.

Problem-based learning (PBL) has been advocated in K-12 contexts as a means to promote understanding, integration, and retention of concepts (Gallagher, 1997; Gallagher, Sher, Stepien, & Workman, 1995). Through analysis of the problem, students acquire both relevant knowledge and problem-solving skills (Barrows & Tamblyn, 1980). However, implementing problem-based learning presents several challenges to the learner, who may become overwhelmed in this unfamiliar context (Land, 2000). Scaffolds, defined as tools, strategies, or guides, may be one means of supporting learners in PBL. In this review, we present a number of scaffolding strategies endorsed by teachers, designers, and researchers. Specifically, scaffolds have the potential to support learner performance by accomplishing at least three crucial goals: 1) initiating students' inquiry; 2) aiding learners with concept integration and addressing misconceptions; and 3) promoting reflective thinking. The primary focus of our paper is to explore how scaffolds can serve to support each of these purposes, and to present examples that might assist researchers, instructional designers, and teachers who advocate PBL as a beneficial instructional approach.

Theory of Action Statement 6

When teachers relate lessons to prior knowledge, students are more likely to engage in the lesson and achieve the intended learning goals.

1. A Learning Progression for Scientific Argumentation: Understanding Student Work and Designing Supportive Instructional Contexts

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. Science Education 94(5), 765-793. URL

Argumentation is a central goal of science education because it engages students in a complex scientific practice in which they construct and justify knowledge claims. Although there is a growing body of research around argumentation, there has been little focus on developing a learning progression for this practice. We describe a learning progression to understand both students' work in scientific argumentation and the ways in which the instructional environment can support students in that practice. This learning progression describes three dimensions: (1) instructional context, (2) argumentative product, and (3) argumentative process. In this paper, we compare four examples from elementary, middle, and high school science classrooms to explore the ways in which students' arguments vary in complexity across grade level and instructional contexts. Our comparisons suggest that simplifying the instructional context may facilitate students in engaging in other aspects of argumentation in more complex ways. The instructional context may also be used as a tool to support students in argumentation in new content areas and to increase the complexity of their written arguments, which may be weaker than their oral arguments. Furthermore, classroom norms play an important role in supporting students of all ages, including elementary students, in argumentation.

2. How Does Prior Knowledge Influence Learning Engagement? The Mediating Roles of Cognitive Load and Help-Seeking

Dong, A., Jong, M. S. Y., & King, R. B. (2020). How does prior knowledge influence learning engagement? The mediating roles of cognitive load and help-seeking. *Frontiers in psychology*, *11*, 591203.

Learning engagement is strongly influenced by prior knowledge. However, past studies on engagement have failed to take this into account. Our findings indicate that cognitive load plays a crucial role in the relationship between prior knowledge and learning engagement via help-seeking behaviors. Paradoxically, it is students who least need help because they already know more (high prior knowledge) are also more likely to engage in adaptive instrumental help-seeking. Conversely, students who most needed help because they knew less (low prior knowledge) were less likely to seek help or seeking or engage in executive help-seeking. A practical implication of this study is that teachers should pay attention to adjusting the level of cognitive load through their instructional design to facilitate students' instrumental help-seeking thereby promoting learning engagement.

3. Science Achievement Gaps Begin Very Early, Persist, and Are Largely Explained by Modifiable Factors

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher*, *45*(1), 18-35.

We examined the age of onset, over-time dynamics, and mechanisms underlying science achievement gaps in U.S. elementary and middle schools. To do so, we estimated multilevel growth models that included as predictors children's own general knowledge, reading and mathematics achievement, behavioral self-regulation, sociodemographic, other child- and family-level characteristics (e.g., parenting quality), and school-level characteristics (e.g., racial, ethnic, and economic composition; school academic climate). Analyses of a longitudinal sample of 7,757 children indicated large gaps in general knowledge already evident at kindergarten entry. Kindergarten general knowledge was the strongest predictor of first-grade general knowledge, which in turn was the

strongest predictor of children's science achievement from third to eighth grade. Large science achievement gaps were evident when science achievement measures first became available in third grade. These gaps persisted until at least the end of eighth grade. Most or all of the observed science achievement gaps were explained by the study's many predictors. Efforts to address science achievement gaps in the United States likely require intensified early intervention efforts, particularly those delivered before the primary grades. If unaddressed, science achievement gaps emerge by kindergarten and continue until at least the end of eighth grade.

4. How People Learn

National Research Council, Donovan, S., & Bransford, J. (2005). *How students learn*. Washington, DC: National Academies Press.

Key Findings:

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information that are taught, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must: (1) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application.
3. A 'metacognitive' approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them.

Implications for Teaching:

1. Teachers must draw out and work with the preexisting understandings that their students bring with them.
2. Teachers must teach some subject matter in depth, providing many examples in which the same concept is at work and providing a firm foundation of factual knowledge.
3. The teaching of metacognitive skills should be integrated into the curriculum in a variety of subject areas.

5. Factors that influence pupil engagement with science simulations: the role of distraction, vividness, logic, instruction and prior knowledge

Rodrigues, S. (2007). Factors that influence pupil engagement with science simulations: the role of distraction, vividness, logic, instruction and prior knowledge. *Chemistry Education Research and Practice*, *8*(1), 1-12.

Constructivist perspectives advocate high quality visual and auditory multimedia to simulate complex and authentic situations. However, the influence of symbolic or representational learning materials on pupil engagement or learning outcomes is not clear. This paper reports on pupil engagement with two types of simulation commonly found in school science (to illustrate practical experiments or depict microscopic chemical interactions). The project pilot phase involved three 15-16 year old male pupils and a main phase involved twenty one 14-15 year old pupils. They were presented with a digital record of their 'think aloud' behaviour with the simulation and they were asked for retrospective comment. Pre and post surveys were also used. Distraction, vividness, logic, instruction and prior knowledge played a significant role in determining the nature of engagement and the outcome of engagement. E-assessment involving multimedia or symbolic representation in science education must take great care if it is to ensure that what it is assessing is the pupil's science capability and not information processing skills that rely on shared symbol identification or on the ability to follow the designers' logic of instructions.

6. The Effect of Ethnoscience-Themed Picture Books Embedded within Context-Based Learning on Students' Scientific Literacy

Yuliana, I., Cahyono, M. E., Widodo, W., & Irwanto, I. (2021). The Effect of Ethnoscience-Themed Picture Books Embedded Within Context-Based Learning on Students' Scientific Literacy. *Eurasian Journal of Educational Research*, *92*, 317-334

Scientific literacy plays an important role in catalyzing science learning in the 21st century. Unfortunately, previous evidence revealed that students' scientific literacy tends to be unsatisfactory. This study investigated the effect of ethnoscience-themed picture books embedded in context-based learning (EthCBL) on students' scientific literacy. Methods: In this quasi-experimental research, 58 (35 girls and 23 boys) fifth-grade students in a public elementary school in Indonesia were selected using purposive sampling. Twenty-nine students (19 girls and 10 boys) were assigned as an experimental group and 29 students (16 girls and 13 boys) were assigned as a control group. The Scientific Literacy Test (SLT) was employed to measure students' scientific literacy in prior and subsequent interventions. Data were analyzed using independent and paired t-tests at the 0.05 significance level. Findings: The results showed that EthCBL was more effective in promoting the scientific literacy of fifth-graders than traditional teaching. After treatment, the experimental group showed higher posttest scores in all sub-scales of scientific literacy compared to the control group. Implications for Research and Practice: In this study, EthCBL was integrated with the surrounding culture that allows students to learn more and participate actively which made their scientific literacy increase. Therefore, it is recommended that teachers apply EthCBL to improve the scientific literacy of elementary school students to a satisfactory level.

Theory of Action Statement 7

When lessons include expectations that students apply scientific practices (e.g. solve problems, engage in argumentation, analyze data, develop and use models), students are more engaged, and deeper understanding and active learning takes place.

1. Teachers and Science Curriculum Materials: Where We Are and Where We Need to Go

Davis, E. A., Janssen, F. J., & Van Driel, J. H. (2016). Teachers and science curriculum materials: Where we are and where we need to go. Studies in Science Education, 52(2), 127–160. URL

Curriculum materials serve as a key conceptual tool for science teachers, and better understanding how science teachers use these tools could help to improve both curriculum design and theory related to teacher learning and decision-making. The authors review the literature on teachers and science curriculum materials. The review is organized around three main questions: What do teachers do when using science curriculum materials? What happens when teachers use science curriculum materials? and Why do teachers make the decisions they do? For each question, the authors first summarize the findings of two key reviews from the mathematics education literature, then situate the findings from science education in juxtaposition with those findings. The review uncovers that relatively little is understood about the mechanism underlying how teachers interact with curriculum materials. To try to address this gap, complementing and extending the field's existing understandings of the teacher–curriculum relationship, the authors make four propositions, grounded in the literature on self-regulation. The propositions reflect a mechanism for teacher curricular decision-making. The self-regulation perspective also helps to develop more targeted support for science teachers aimed at the uptake, adaptation and enactment of curriculum materials in ways that are intended, and that teachers themselves experience as an improvement in their teaching. The authors conclude with a call for research that further explores the ways in which individual science teachers' decision-making is situated within the wider sociocultural context.

2. Children's Understanding of Scientific Inquiry: Their Conceptualization of Uncertainty in Investigations of Their Own Design.

Metz, K. E. (2004). Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. Cognition and instruction, 22(2), 219-290. URL

The study examined children's understanding of scientific inquiry, through the lens of their conceptualization of uncertainty in investigations they had designed and implemented with a partner. These largely student-regulated investigations followed a unit about animal behavior that emphasized the scaffolding of independent inquiry. Participants were children in a 2nd grade class (n = 21) and a combined 4th-5th grade class (n = 31). The primary database consisted of videotaped structured interviews with each pair following completion of their investigation. These interviews were used to analyze whether the child had conceptualized an uncertainty in their study and, if so, the sphere of the uncertainty. This top-level analysis resulted in a taxonomy of 5 spheres of uncertainty: (a) how to produce the desired outcome as uncertain; (b) data as uncertain; (c) trend identified in the data as uncertain; (d) generalizability of this trend as uncertain; and (e) the theory that best accounts for the trend as uncertain. Seventy-one percent of the 2nd graders and 87% of the 4th-5th graders conceptualized 1 or more spheres of uncertainty in their respective research study. Among those who had conceptualized 1 or more spheres of uncertainty, 80% of the 2nd graders and 97% of the 4th-5th graders posited a strategy for how to modify their study to address the uncertainty. Finer grained analysis revealed that in almost every instance the grounds reflected some valid concern and the strategy the child proposed would at least begin to address the identified problem. These analyses indicate that most children developed a rich understanding of how uncertainty enters into scientific inquiry. In this context of reflection on their own scientific inquiry, these children manifested at least a

rudimentary understanding of the complex relation between the natural world and knowledge thereof that transcended a naive realism, and manifested aspects of a "knowledge problematic" epistemological perspective.

3. A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. The National Academies Press. URL

"*A Framework for K-12 Science Education* outlines a broad set of expectations for students in science and engineering in grades K-12. These expectations will inform the development of new standards for K-12 science education and, subsequently, revisions to curriculum, instruction, assessment, and professional development for educators. This book identifies three dimensions that convey the core ideas and practices around which science and engineering education in these grades should be built. These three dimensions are: crosscutting concepts that unify the study of science through their common application across science and engineering; scientific and engineering practices; and disciplinary core ideas in the physical sciences, life sciences, and earth and space sciences and for engineering, technology, and the applications of science. The overarching goal is for all high school graduates to have sufficient knowledge of science and engineering to engage in public discussions on science-related issues, be careful consumers of scientific and technical information, and enter the careers of their choice. *A Framework for K-12 Science Education* is the first step in a process that can inform state-level decisions and achieve a research-grounded basis for improving science instruction and learning across the country. The book will guide standards developers, teachers, curriculum designers, assessment developers, state and district science administrators, and educators who teach science in informal environments.

4. Developinga Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 46(6), 632-654. URL

Students were able to construct models that were abstracted to some extent from the specifics of the phenomena they studied and captured important explanatory mechanisms and relationships between the components (e.g., water particles moving from liquid to gas, odor particles in motion, colliding with air particles). Students were able to use models to make predictions about closely related phenomena, drawing directly on the explanations captured in the models to make predictions for a new situation. They were able to evaluate and compare models and determine which aspects to include in a consensus model. Finally, they were able to revise their models when learning more about the phenomena, and constructed multiple models that successively increased in sophistication. Furthermore, there is initial evidence that students were developing some aspects of the important understandings about this practice.

5. Preservice Science Teachers Practice Teaching Online through 4E Instructional Model

Sengul, O. (2021). Preservice science teachers practice teaching online through 4E instructional model breadcrumb. Journal of College Science Teaching, 51(1). URL

This article is prepared as part of a "Practice Teaching in Science" course of a teacher education program aiming for developing prospective science teachers' teaching through inquiry-based instruction involving practices of science and active learning strategies. During the semester, student teachers are required to prepare four 50-minute lesson plans on different topics. The author, a teacher educator, explains how to plan and implement science lessons virtually through the 4E instructional model: engagement, exploration, explanation, and evaluation.

Theory of Action Statement 8

When lessons include frequent opportunities for scientific discourse (e.g., sharing ideas during the investigation, making predictions, arguing for ideas using evidence, synthesizing findings), teachers can support students in developing and deepening their understanding of scientific ideas.

1, A Systematic Review of Science Discourse in K–12 Urban Classrooms in the United States: Accounting for Individual, Collective, and Contextual Factors

Bae, C. L., Mills, D. C., Zhang, F., Sealy, M., Cabrera, L., & Sea, M. (2021). A systematic review of science discourse in K–12 urban classrooms in the United States: Accounting for individual, collective, and contextual factors. Review of Educational Research, 91(6), 831-877. URL

The literature on science discourse in K–12 classrooms in the United States has proliferated over the past couple of decades, crossing geographical, disciplinary, theoretical, and methodological boundaries. There is general consensus that science talk is at the core of students' learning; however, a synthesis of key findings from the expansive literature base is needed. This systematic literature review is guided by a complex systems framework to organize and synthesize empirical studies of science talk in urban classrooms across individual (student or teacher), collective (interpersonal), and contextual (sociocultural, historical) planes. Findings are discussed in relation to contemporary approaches that integrate theories and methodologies to account for the complex phenomena of science discourse, including interacting elements across levels as well as stable and changing patterns that influence students' access to, and nature of, science talk in urban classrooms. Unresolved questions related to high-leverage, equitable, and sustainable discourse practices; future lines of inquiry that can benefit by drawing from diverse theoretical traditions and mixed methodological approaches; and practical implications for classroom-based strategies to support science discourse are also discussed.

2, Next Generation Science Standards in Practice: Tools and Processes Used by the California NGSS Early Implementers

Cerwin, K., DiRanna, K., Grace, J., LaFontaine, P., Ritchie, S., Sherif, J., Topps, J., Tupper, D., Vargas, C., Woods, B., Tyler, B., Britton, T. & Iveland, A. (2018). Next Generation Science Standards in practice: Tools and processes used by the California NGSS early implementers. WestEd. URL

NGSS Early Implementers is a four-year initiative created to help eight California school districts and two charter management organizations, supported by WestEd's K-12 Alliance, implement the Next Generation Science Standards (NGSS). Designed for professional developers and administrators, this report describes 10 tools and processes that are central in the professional learning provided to teachers and administrators in the participating school districts. The tools and processes are designed to aid NGSS lesson planning, NGSS instruction, and administrator support during implementation. The 10 tools and processes presented in the publication are: (1) Criteria for Choosing Phenomena; (2) Phenomena-Based, Three-Dimensional Conceptual Flow; (3) 5E Instructional Model for Developing Learning Sequences; (4) Teaching Learning Collaborative (TLC); (5) Looking at Student Work; (6) Questioning Strategies that Promote Student Discourse; (7) Sense-Making Student Notebooks; (8) Principal Academy; (9) Walk-Through Protocol; and (10) Evidence of Learning Protocol. All tools and processes were created or adapted to be used explicitly for supporting NGSS implementation. The report describes each item, how it has been used, and how participants are benefitting from it. Other districts and schools can learn from, draw upon, and adapt the items to support their own implementation efforts.

3. Rigor in Elementary Science Students' Discourse: The Role of Responsiveness and Supportive Conditions for Talk

Colley, C., & Windschitl, M. (2016). Rigor in elementary science students' discourse: The role of responsiveness and supportive conditions for talk. Science Education, 100(6), 1009–1038. URL

Teaching that is responsive to students' ideas can create opportunities for rigorous sense-making talk by young learners. Yet we have few accounts of how thoughtful attempts at responsive teaching unfold across units of instruction in elementary science classrooms and have only begun to understand how responsiveness encourages rigor in conversations. In this study, the first author taught an electric circuits unit to four upper elementary science classes, exercising a responsive teaching stance. We found that rigorous episodes of whole-class talk were associated with the teacher's use of open-ended questions, follow-up prompts, references to activity or representations, prediscussion tasks, and asking students to comment on their peers' ideas. Overall, higher rigor talk co-occurred with these conditions when used in combination. Despite being responsive to students' emerging ideas, all four classes addressed the science ideas for the unit--an outcome we attribute to the use of an anchoring phenomenon and the teacher's awareness of the concepts required to construct evidence-based explanations for it. Finally, concerted attempts to teach in responsive ways--while also attending to rigor--surfaced pedagogical tensions that problematize efforts to create such discourse-rich environments and inform how this type of instruction might be enacted by others.

4. Exploring the Form and the Function: A Review of Science Discourse Frameworks in the Service of Research and Practice

Criswell, B. A., Rushton, G. T., & Shah, L. (2021). Exploring the form and the function: A review of science discourse frameworks in the service of research and practice. Research in Science Education, 51(1), 209-224. URL

The importance of how classroom discourse can be used to support science learning has gained national attention with respect to both science teaching and research across K12 and higher education. In this review article, we examine a commonly referenced set of nine frameworks for use in *science* classrooms. Specifically, we examine the ways in which various frameworks emphasize the structure (i.e., *form*) or practical use (i.e., *function*) of language across classroom settings, and the impact of such an emphasis on the facilitation and analysis of science classroom discourse. The findings from this review should help researchers investigate and educators facilitate classroom discourse in ways that ensure that all students can participate in and demonstrate their scientific understanding.

5. Discourse in Science Classrooms

Kelly, G. J. (2013). Discourse in science classrooms. Handbook of Research on Science Education, 457-484. URL

Educational events occur through communication. Science learning can be conceptualized as students coming to know how to use specialized language, given the constraints of particular social configurations and cultural practices. Across different theoretical traditions, from the sociology and rhetoric of science to studies of classroom interaction, the importance of spoken and written discourse in the production and learning of disciplinary knowledge is becoming increasingly recognized as a salient research focus. The study of discourse, broadly defined, allows researchers to examine what counts as science in given contexts, how science is interactionally accomplished, who participates in the construction of science, and how situated definitions of science imply epistemological orientations. In this chapter, I provide a conceptual overview of the field of discourse studies in science education. My aim is not to present a comprehensive review of all studies, but rather to focus on some of the theoretical approaches, methodological orientations, and substantive findings. Through this selected review, I argue that a discourse analytic perspective provides insight into how the events that make up science education are constructed through language and social processes. The importance of viewing education through this lens of language and social processes is justified by three primary observations. First, teaching and learning occur through processes constructed through discourse and interaction. An empirical focus on the ways language contributes to learning is essential for developing theories of practice for science education. Second, student access to science is accomplished through engagement in the social and symbolic worlds comprising the knowledge and practices of specialized communities. Issues of understanding, appropriating, affiliating, and developing identities for participation in the knowledge and practices of the sciences can be understood through the study of discourse processes. Third, disciplinary knowledge is constructed,

framed, portrayed, communicated, and assessed through language, and thus understanding the epistemological base of science and inquiry requires attention to the uses of language. I conclude this review with implications about how the current body of knowledge suggests future directions for research in discourse processes in science education settings.

6. Engineering Design in the Elementary Science Classroom: Supporting Student Discourse during an Engineering Design Challenge

McFadden, J., & Roehrig, G. (2019). Engineering design in the elementary science classroom: Supporting student discourse during an engineering design challenge. International Journal of Technology and Design Education, 29(2), 231-262. URL

This exploratory case study examines how various instructional strategies can influence elementary-aged student discourse patterns during an engineering design challenge. With engineering design increasingly entering the elementary science classroom both within the United States and internationally, students must now engage in discipline-specific "practices" intended to mirror the work of professional engineers. The current study analyzed classroom discourse over the length of an instructional unit using an analytical lens informed by Heath's (in: Masten (ed) The Minnesota symposia on child psychology, Psychology Press, New York, pp. 59-75, 1999) concept of "joint work," which revealed how three parallel and complimentary discourse practices emerged primarily and more readily once students were given access to the materials needed for their mining extraction tool. The study's findings illustrate the importance of designing and implementing pedagogical supports capable of ensuring students understand how their drawn designs can be used (Henderson in Sci Technol Hum Values 16(4):448-473, 1991) to manage the uncertainty that naturally arises during an engineering design challenge. Furthermore, the results point to the need for further research at the classroom level that investigates how students can be better supported to overcome the challenges associated with design-based problem solving, possibly via the inclusion of written, rather than verbal support.

7. Literacy for Science: Exploring the Intersection of the Next Generation Science Standards and Common Core for ELA Standards: A Workshop Summary

National Research Council (2014). Literacy for science: Exploring the intersection of the Next Generation Science Standards and Common Core for ELA standards: A workshop summary. National Academies Press. URL

The recent movement in K-12 education toward common standards in key subjects represents an unprecedented opportunity for improving learning outcomes for all students. These standards initiatives - the Common Core State Standards for English Language Arts and Mathematics (CCSS) and the Next Generation Science Standards (NGSS) - are informed by research on learning and teaching and a decade of standards-based education reform. While the standards have been developed separately in English/Language Arts and Science, there are areas where the standards intersect directly. One such area of intersection occurs between the "Literacy in Science" portions of the Common Core State Standards for English/Language Arts and the practices in the NGSS (originally outlined in the NRC's A Framework for K-12 Science Education), particularly the practice of "Obtaining, evaluating and communicating information.

8. Discourse Strategies for Science Teaching and Learning: Research and Practice

Tang, K. S. (2020). Discourse strategies for science teaching and learning: Research and practice. Routledge. URL

This engaging and practical volume looks at discourse strategies and how they can be used to facilitate and enhance science teaching and learning within the classroom context, offering a synthesis of research on classroom discourse in science education as well as practical discourse strategies that can be applied to the classroom.
Focusing on the connection between research and practice, this comprehensive guide unpacks and illustrates key concepts on the role of discourse in students' thinking and learning based on empirical analysis of real conversations in a number of science classrooms. Using real-life classroom examples

to extend the scope of research into science classroom discourse begun during the 1990s, Kok-Sing Tang offers original discourse strategies as explicit methods of using discourse to engage in meaning-making and work towards a specific instructional goal. This volume covers new and informative topics including how to use discourse to:

- Establish classroom activity and interaction
- Build and assess scientific content knowledge
- Organize and evaluate scientific narrative
- Enact scientific practices
- Coordinate the use of multimodal representations

Building on more than ten years of research on classroom discourse, Discourse Strategies for Science Teaching and Learning is an ideal text for science teacher educators, pre-service science teachers, scholars, and researchers.

Theory of Action Statement 9

When district and school-based leaders invest in, prioritize, and support the use of research-based, digital learning resources by teachers and students, engagement and achievement increases.

1. Best Practices of Leadership in Educational Technology

Brown, L. (2014). Best practices of leadership in educational technology. Journal of Educational Technology, 11(1), 1-6. URL

Leadership in Educational Technology is a relatively new field that is changing as fast as technology itself. Success for an educational leader includes maintaining a firm grasp of how to diagnose the needs of a district, a school, or aclassroom while aligning policies, procedures, and protocols into a format that will empower the individual teacher efficacy and student learning outcomes. Being a leader in educational technology includes more than incorporating new technologies into the classroom. Leadership in educational technology requires an outlook that views technology not as a tool for every occasion, but as a tool that when used, will enhance the learning process. An approach of best practices is essential to maintain effectiveness as an educational leader, and yet there is very little research that includes a synthesis of the best practices or approaches that are certain to increase an educational leader's effectiveness. A best practices approach that relies on the use of constructivist teaching method, that strives for continuous improvement through the use of professional learning networks and communities, and that utilizes online professional development will produce the kind of effectiveness in teachers that is associated with positive student learning outcomes.

2. Beyond the Classroom: A Framework for Growing School Capacity in a Digital Age

Haynes, C. A., & Shelton, K. (2018). Beyond the classroom: A framework for growing school capacity in a digital age. Journal of Research on Technology in Education, 50(4), 271-281.

Rapid technological advancements promise unprecedented educational opportunities to foster student-centeredand personalized learning, yet many schools are underprepared, lacking comprehensive organizational strategies for technology enhanced learning. This study sought to provide a framework to guide K-12 school leaders to buildand evaluate digital-age school capacity by identifying essential criteria for digital learning in schools, resulting in the development of the Digital Learning Implementation Framework for Education (D-LIFE). Geographically dispersed digital learning experts contributed to a six-round Delphi study gaining consensus on 148 essential criteria for school administrators and policymakers to appraise strategic evaluation of technology implementation. When compared to prominent frameworks, D-LIFE confirmed high-level alignment with ISTE Essential Conditions, providinga comprehensive evaluation framework for K–12 schooling not addressed in prominent standards or frameworks.

3. Leading Technology-Rich School Districts: Advice from Tech-Savvy Superintendents

McLeod, S., Richardson, J. W., & Sauers, N. J. (2015). Leading technology-rich school districts: Advice from tech-savvy superintendents. Journal of Research on Leadership Education, 10(2), 104-126. URL

Superintendents' instructional leadership is critical to the academic success of school systems. In addition to traditionalwork complexities, today's superintendents must navigate rapid and significant technological transformations. In this study, an exploratory sample of "technology-savvy" superintendents was interviewed to ascertain advice about how to navigate the complexities that surround successful district-level technology leadership strategies and mind-sets. Participants highlighted issues such as budgets, professional development, and instructional leadership, and affirmed the value of personally modeling technology use. They also emphasized both personal and organizational risk-taking andshared how communities of practice can help alleviate skill and knowledge gaps.

4. Leadership Practice in a One-to-one Computing Initiative: Principals' Experiences in a Technology Driven, Second-order Change

Pautz, S., & Sadera, W. A. (2017). Leadership practice in a one-to-one computing initiative: Principals' experiences in a technology driven, second-order change. Computers in the Schools, 34(1-2), 45-59.

School districts have been placed under increasing pressure to equalize student access to technology and equip students with the skills necessary to be competitive in a global economy. In response, a growing number of schools have sought an irreversible and dramatic departure from past practices, a second-order change, to learner-centered environments powered by one-to-one computing. While one-to-one computing has drawn the attention of researchers for more than 30 years, the field has not examined principals' experiences in leading the implementation of such an initiative. Yet leadership research continually affirms the importance of the principal in effective change implementation.This article discusses the findings of a study that explored principals' experiences leading the changes associated with a one-to-one initiative and the contexts or situations that influenced those experiences. Using a phenomenological method, this study explored how eight elementary school principals leading a one-to-one initiative viewed their role and responsibilities, promoted change, and responded to successes and challenges. This study provides new insights into change leadership that will inform practice in the leadership of one-to-one computing initiatives.

5. District Technology Leadership Then and Now: A Comparative Study of District Technology Leadership from 2001 to 2014

Richardson, J. W., & Sterrett, W. L. (2018). District technology leadership then and now: A comparative study of district technology leadership from 2001 to 2014. Educational Administration Quarterly,54(4), 589-616. URL

This article focuses on district superintendents who were recognized as eSchool News Tech-Savvy Superintendents. Research Methods: Using interviews, this study compares data from superintendents who won this award between 2001and 2010 in contrast to those who won the award between 2011 and 2014. The focus of the study is on understanding how discussions of challenges and successes within this population have shifted over nearly 15 years…A key finding is that these district-level leaders have shifted away from first-order changes of implementing technology initiatives and toward second-order changes of supporting teaching and learning that is supported with modern digital technologies.

6. The Principal's Role in Supporting a School's Technology Culture: A Mixed Methods Study

Sawicki, J. H. (2021). The Principal's Role in Supporting a School's Technology Culture: A Mixed Methods Study (Publication No. 28648377). [Doctoral dissertation, Delaware Valley University. ProQuest.

This mixed methods exploratory sequential study investigated the principal's role in supporting a school's technology culture. In light of the 2019-2020 worldwide pandemic, schools around the world saw a significant increase put on technology tools to facilitate instruction virtually. As building leaders, the administrators led the transition to fully virtual instruction by supporting their teachers...the researcher collected data from K-12 principals and assistant principals in a targeted six county area of eastern Pennsylvania. This study used a survey along with semi-structured interviews. The pandemic closure of 2019-2020 provided a unique opportunity to understand principals' knowledge of the ISTE-EL Standards, to identify how they demonstrate implementation of the ISTE-EL Standards, to see if they value technology ascurriculum tool, and to see how prepared building leaders were for the sudden shift to fully virtual instruction. Overall, this study revealed that administrators have knowledge of the ISTE-EL standards as measured by their responsesto 45 questions on the survey. Two themes emerged from the interview data that highlighted elements of the principals' implementation of the ISTE-EL Standards: access to the internet and professional development and collaboration. Interview data revealed that these administrators, as a whole, value technology as a curriculum tool. In schools where one-to-one programs were already in place, their perception was that they were prepared to make the shift to fully virtualinstruction.

7. An Analysis of Factors which Influence High School Administrators' Readiness and Confidence to Provide Digital Instructional Leadership

Shepherd, A. C., & Taylor, R. T. (2019). An Analysis of Factors Which Influence High School Administrators' Readiness and Confidence to Provide Digital Instructional Leadership. International Journal of Educational Leadership Preparation, 14(1), 52-76. URL

School leaders are to be instructional leaders within a digital environment, just as they are expected to do in the non- digital environment. The purpose of this study was to analyze the factors which high school administrators perceive to influence their knowledge and confidence to lead in a digital school environment. Findings suggest that administratorsshould seek professional development opportunities, knowledgeable and confident colleagues, and opportunities to supervise others to increase knowledge and confidence.

8. Reimagining the Role of Technology in Education: 2017 National Education Technology Plan Update

U.S. Department of Education. (2017). Reimagining the role of technology in education: 2017 National Education Technology Plan update. URL

The National Education Technology Plan (NETP) sets a national vision and plan for learning enabled by technology through building on the work of leading education researchers; district, school, and higher education leaders; classroom teachers; developers; entrepreneurs; and nonprofit organizations. The principles and examples provided in this document align to the Activities to Support the Effective Use of Technology (Title IV) Part A of the Elementary and Secondary Education Act (ESEA), as amended by Every Student Succeeds Act (ESSA). To illustrate key ideas and recommendations, the plan includes examples of the transformation enabled by the effective use of technology. These examples include both those backed by rigorous evidence as well as emerging innovations. The identification of specific programs or products in these examples is designed to provide a clearer understanding of innovative ideas. The NETP also provides actionable recommendations to implement technology and conduct research and development successfully that can advance the effective use of technology to support learning and teaching. This 2017 update to the NETP is the first yearly update in the history of the plan.

9. Contemporary Science Practice in the Classroom: A Phenomenological Exploration into How Online Curriculum Resources Can Facilitate Learning

Vamvakas, M., White, P., & Tytler, R. (2021). Contemporary science practice in the classroom: A phenomenological exploration into how online curriculum resources can facilitate learning. International Journal of Science Education, 43(13), 2087-2107. URL

Using a phenomenological lens, we investigated how online curriculum resources can support secondary science teachers to explore contemporary science practices with their students. The research used a social constructivist theoretical and a hermeneutic phenomenology methodological framework to describe and interpret the teacher/participants' experience. Seven participants teaching science to Year 7-10 students (12-15 years old) engaged in the research project, trialing selected contemporary science resources in their class. Pre and post intervention interviews were conducted with each participant along with classroom observations of one lesson to view aspects of the effectiveness of the resource, the teachers' approach and their perceptions of student learning and engagement. Discussion focuses on how the online curriculum resources presented alternative views about science in practice to what students expect, providing an in-depth view of scientists and their research practices in varied settings. Affordances of this approach for bringing real science into the classroom and for improving student engagement and learning are considered. The findings point to the approach being potentially a productive, scalable way forward for introducing contemporary science practice into classrooms. We advocate further research investigating the potential of this type of online curriculum resource to connect students more powerfully with scientists and their practices.

Theory of Action Statement 10

When district and school-based leaders prioritize science education by providing effective professional development, high-quality curricular resources, and ample instructional time, students are more likely to engage in science and achieve the intended learning goals.

1. Science Instructional Time is Declining in Elementary Schools: What are the Implications for Student Achievement and Closing the Gap?

Blank, R. K. (2013). Science instructional time is declining in elementary schools: What are the implications for student achievement and closing the gap? *Science Education*, *97*(6), 830-847.

Recent comparative data on high school graduates show that many American students are not well prepared in fields of science, technology, engineering, and mathematics and that there is a persistent achievement gap according to the socioeconomic backgrounds of students. The research for this paper focuses on the role of elementary education in science as an important preparatory step. National trend data show a decline in instructional time in the elementary grades on science instruction over the past two decades. State-level data show wide variation in the amount of class time spent on science education and a positive relationship between the amount of class time and student achievement scores in science as measured by the National Assessment of Educational Progress Grade 4 assessment.

2. The More, The Better? The Impact of Instructional Time on Student Performance

Cattaneo, M. A., Oggenfuss, C., & Wolter, S. C. (2017). The more, the better? The impact of instructional time on student performance. Education economics, 25(5), 433-445.

Building on earlier work that explored within-student variation in hours of instruction across school subjects, we investigate the impact of instruction time on student test scores in Switzerland, as measured by the PISA 2009 test. Our results confirm the results of previous studies of a positive effect of instruction time on student performance. Moreover, we find considerable heterogeneity in the effectiveness of instructional time across ability-related tracks, with the more able students benefitting more. Additional instruction time increases the within-school variance of subject-specific test scores, indicating an increase in educational inequality.

3. An analysis of science instruction for the science practices: Examining coherence across system levels and components in current systems of science education in K-8 schools

Cherbow, K., McKinley, M. T., McNeill, K. L., & Lowenhaupt, R. (2020). An analysis of science instruction for the science practices: Examining coherence across system levels and components in current systems of science education in K-8 schools. *Science Education*, *104*(3), 446-478.

Recent reforms in science education advocate for a vision of learning where students *figure out* science ideas through engagement in science practices. Consequently, there have been significant efforts to engage K-12 students in the science practices. However, less research attention has been given to understand how this science-as-practice vision manifests across systems of science education. Therefore, we analyzed how coherence among system levels (vertical coherence) and components (horizontal coherence) emerged in science instruction and influenced alignment to current science practice reform. We situated instruction in school systems by shadowing four school principals as they supervised science teaching over 4 months. In each school, we observed institutional settings where efforts to implement science reform were largely assimilated into the school's current instructional and administrative systems. These systems prioritized the coverage of state test-related information, the promotion of literacy skills, and the importance of “hands-on” science learning. Therefore, we need to create conditions that support educators in translating reform efforts into a reliable working infrastructure in their teaching practice. Further, we suggest greater

attention be given to local protocols to collectivize action across system levels and components to develop coherent and user-centered solutions for implementation of science reform.

4. Time to Teach: Instructional Time and Science Teachers' Use of Inquiry-oriented Instructional Practices

Kolbe, T., Steele, C., & White, B. (2020). Time to teach: Instructional time and science teachers' use of inquiry-oriented instructional practices. Teachers College Record, 122(12), 1-54.

This study investigates the relationship between the time available for science instruction and the extent to which eighth-grade science teachers used inquiry-oriented instructional practices in their teaching. We consider two research questions: (1) To what extent is teachers' use of inquiry-oriented instructional practices related to the time available for science instruction during the school week? (2) To what extent do differences in teachers' professional training to teach science impact the relationship between instructional time and science teachers' use of inquiry-based instructional practices? We use data from the 2011 NAEP Grade Eight Science Assessment and multilevel linear modeling to analyze the relationship between instructional time and science teacher practices. Our analyses include approximately 11,520 eighth-grade teachers in 6,850 public schools. The extent to which science teachers used inquiry-oriented instructional practices in their teaching was related to the amount of time available for science instruction. Teachers with 5 or more hours per week were more likely to use inquiry-oriented instructional practices, and the extent to which teachers engaged in reform-oriented science instruction increased with more time for instruction. The relationship between instructional time and teacher practice was largely independent of teacher qualifications, suggesting that instructional time impacts teacher instructional practice regardless of teachers' educational background, training, or science teaching experience. Identifying optimal allocations of instructional time is a relevant consideration in efforts to promote the types of reform-oriented science teaching called for by the National Research Council's Framework for K–12 Science Education, the Next Generation Science Standards (NGSS), and other national and state science assessments. Although investments in teacher training and professional development are also necessary and important investments, with insufficient time, even the most qualified or best trained science teachers may struggle to use inquiry-based instructional approaches.

5. Subject-Specific Instructional Leadership in K8 Schools: The Supervision of Science in an Era of Reform

Lowenhaupt, R., & McNeill, K. L. (2019). Subject-specific instructional leadership in K8 schools: The supervision of science in an era of reform. *Leadership and Policy in Schools*, *18*(3), 460-484.

Purpose: In U.S. public schools, principals must implement reforms that require instructional leadership across subjects, though little is known about subject-specific supervision. *Methods*: Through interviews with 26 K–8 principals, we examine instructional leadership for science. *Findings*: Our findings showed that science supervision occurred rarely; principals used a "content-neutral" approach that did not emphasize science-specific aspects of instruction. Principals explained this in terms of external accountability pressures in literacy and mathematics, as well as their own lack of science knowledge. *Implications*: We argue for subject-specific resources for principal supervision. For classrooms to change, principals must provide subject-specific support for teachers.

6. How Principal Characteristics Including Experience, Leadership Style, Philosophy, and Education Influence Science Achievement

Lirio, P. (2022). How Principal Characteristics Including Experience, Leadership Style, Philosophy, and Education Influence Science Achievement.

The purpose of this evaluation was to analyze the leadership characteristics of principals and determine how the characteristics influenced science achievement. The context of this inquiry was a school system in the southern United States where 55% of elementary students scored below grade level on the end-of-grade science assessment compared to the state average of 36%. I conducted a mixed-method study using extant science achievement data, science teacher survey data, principal survey data, and principal interview data. The survey and interview data demonstrated a disconnect

between teachers' perceptions and principals' perceptions of science leadership provided by the principals. I recommended a policy to improve science scores by providing professional development for principals. The policy included eight action steps to improve student proficiency in science: analyze science performance, set science goals, define instructional practices, establish clear priorities and parameters in which to act, build instructional capacity in the principals, establish indicators to monitor, align leadership behaviors to facilitate the change, and celebrate small wins (Odden, 2012; Kotter, 2012).

7. Leading Learning in Content Areas: A Systematic Review of Leadership Practices Used in Mathematics and Science Instruction

Lochmiller, C. R., & Cunningham, K. M. (2019). Leading learning in content areas: A systematic review of leadership practices used in mathematics and science instruction. *International Journal of Educational Management*.

The purpose of this paper is to report findings from a systematic literature review that explore how recent research on instructional leadership has addressed the role of mathematics and science instruction. Using Hallinger's (2014) approach to conducting systematic reviews, the review included 109 peer-reviewed articles published since 2008 in leading mathematics and science education journals. An *a priori* coding scheme based upon key leadership behaviors articulated in Hitt and Tucker's (2016) unified leadership framework informed the analysis presented. Results indicate that leaders support content area instruction by facilitating high-quality instructional experiences through curricular and assessment leadership. Leadership frequently involves establishing organizational conditions that support teachers' efforts to improve their own practice instead of direct leadership action on the part of instructional leaders. This support takes different forms and can include distributing leadership to teacher leaders with content area experience as well as using resources strategically to provide professional development or instructional coaching. The review strengthens the connections between the instructional leadership, mathematics and science literatures, and identifies some of the leadership practices that these literatures deem important for instructional improvement. The review also reveals the potential for future research exploring the influence of a particular content area on supervisory practice and leadership discourse.

8. The effect of professional development on elementary science teachers' understanding, confidence, and classroom implementation of reform-based science instruction

Maeng, J. L., Whitworth, B. A., Bell, R. L., & Sterling, D. R. (2020). The effect of professional development on elementary science teachers' understanding, confidence, and classroom implementation of reform-based science instruction. *Science Education*, *104*(2), 326-353.

Through a randomized controlled trial, this mixed-methods study evaluated changes in elementary science teachers' understandings, confidence, and classroom implementation of problem-based learning (PBL), inquiry, and nature of science (NOS) instruction following participation in a professional development (PD) as well as the components of the PD that teachers perceived facilitated these changes. Results indicated that following the PD, treatment teacher ($n = 139$) understandings of and confidence for teaching inquiry, NOS, and PBL were significantly greater than control teachers ($n = 98$) after controlling for preunderstandings and confidence. The effect sizes were large. Treatment teachers also incorporated significantly more PBL, inquiry, and NOS into their instruction. Modeling, microteaching with feedback and reflection, and in-classroom coaching facilitated teachers' confidence, understanding, and intention to implement the reform-based practices they learned. Implications for the understanding of the relationship between knowledge, confidence, and practice as well as elementary science teacher PD design are discussed.

Theory of Action Statement 11

When district and school-based leaders invest in digital resources that are intuitive for users, teachers are more likely to use them for teaching and learning.

1. Teachers' Beliefs about the Role of Digital Educational Resources in Educational Practice

Alberola-Mulet, I., Iglesias-Martínez, M. J., & Lozano-Cabezas, I. (2021). Teachers' beliefs about the role of digital educational resources in educational practice: A qualitative study. *Education Sciences*, *11*(5), 239.

Information and Communication Technologies and Digital Educational Resources have undergone a rapid evolution and have been swiftly introduced into educational contexts. Teachers play a key role in integrating these technological resources into the classroom. The objective of the present study was to determine the value that teachers attribute to digital resources in their educational practice. Based on a qualitative methodology, the necessary information was obtained via an open-ended interview, in which a Spanish school's Early Childhood and Primary Education teachers participated. The results revealed that teachers value the integration of digital resources into the classroom, though no consensus was reached as to the suitable level of integration. Use satisfaction was mainly related to student motivation. Certain problems or limitations also came to light, however, linked to students' digital training. An important conclusion according to the perception of teachers is that the integration of digital resources in their educational practice was significant and improved the quality of the educational process.

2. Exploring Ease of Use, Usefulness, Relevance, Self-Efficacy, and Past Experiences to Describe Influences on Elementary Teachers' Acceptance of Digital Game-Based Materials

Simpson, A. L. (2022). Pursuing Perceptions: Exploring Ease of Use, Usefulness, Relevance, Self-Efficacy, and Past Experiences to Describe Influences on Elementary Teachers' Acceptance of Digital Game-Based Materials.

There are many acceptance factors that might influence teachers' intent to create instruction supplemented or enhanced with digital game-based materials (DGBM). A mixed-methods exploration of five research questions was used to describe how teachers' perceived ease of use, self-efficacy beliefs, opinions about usefulness, perceptions of relevance, and past experiences informed their acceptance of digital game-based materials. This research study took place at Hill Street Elementary School, which is a suburban K-5 school within the Kaia County School District. Data collection was conducted using a survey, one-on-one interviews, and fieldnotes. A purposeful sample of nine interview participants from grades K-4, and 18 survey participants from grades K-5 was used. Teachers' high agreement with statements of perceived self-efficacy and perceived ease of use were shown to be the most influential on DGBM acceptance. Perceived usefulness and perceived relevance were shown to moderately influence acceptance. Experience was the least influential construct tested in the study. Qualitative analysis identified three themes: (1) self-efficacy and issues with use influenced teachers' views about DGBM; (2) effort and engagement influenced the use of adaptive learning games; and (3) independent learning opportunities and curriculum connections influenced acceptance of DGBM. Adaptive learning games made DGBM easier to use, but student technology proficiency decreased ease of use. Self-efficacy influenced teacher acceptance of DGBM but was mediated by teacher beliefs about how to implement DGBM and teaching students how to play the game. Perceived usefulness was controlled by motivation and engagement. Perceived relevance was affected by limitations of curricular connections in DGBM. Digital game-based learning experiences teachers allowed for their students influenced acceptance of DGBM more than teachers' personal gaming experience.

3. Examining Changes in Teachers' Perceptions of External and Internal Barriers in Their Integration of Educational Digital Resources in K-12 Classrooms

Xie, K., Nelson, M. J., Cheng, S. L., & Jiang, Z. (2023). Examining changes in teachers' perceptions of external and internal barriers in their integration of educational digital resources in K-12 classrooms. *Journal of Research on Technology in Education*, *55*(2), 281-306.

This study examined changes in teachers' perceptions of external barriers, internal barriers, and their integration of digital educational resources across two years through variable-centered and person-centered approaches. Participants included 301 in-service middle and high school teachers from 18 schools in the United States. The results of variable-centered approaches showed some significant changes in external barriers and teacher behavior but not in internal barriers. However, person-centered approaches revealed that perceived changes in external barriers significantly predicted nuanced changes in the patterns of teachers' educational digital resource integration and their beliefs about technology. As teachers perceived a stronger technology vision and commitment to professional development in their school environments, their personal practices and beliefs shifted together.