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Inquiry Learning and Opportunities for Technology

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Abstract 120-150 words [147 words]

To synthesize research on inquiry learning, we integrate advances in theory, instructional design, and technology. We illustrate how inquiry instruction can exploit the multiple, often conflicting ideas that students have about personal, societal, and environmental dilemmas and promote coherent arguments about economic disparity or health decision-making. We show how technologies such as natural language processing, interactive simulations, games, collaborative tools, and personalized guidance can support students to become autonomous learners. We discuss how these technologies can capture class performance and inform teachers of student progress. We highlight autonomous learning from (a) student-initiated investigations of thorny, contemporary problems using modeling and visualization tools, (b) design projects featuring analysis of alternatives, testing prototypes, and iteratively refining solutions in complex disciplines, and (c) personalized guidance that encourages gathering evidence from multiple sources and refining ideas. We argue that autonomous inquiry capabilities empower all citizens to take charge of their lives.

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Inquiry Learning and Opportunities for Technology

Whether in history, science, journalism, economics, or other disciplines, inquiry activities engage learners in exploring meaningful problems, testing conjectures about relationships among variables, comparing alternative explanations (often by building and testing models), using evidence to refine ideas, and developing arguments for promising solutions (Furtak, Seidel, Iverson & Briggs, 2012). Inquiry instruction can exploit the multiple, often conflicting ideas that students have about personal, societal, and environmental dilemmas, and help them to sort out these ideas to address challenges such as economic disparity or health decision-making (Donnelly, Linn & Ludvigsen, 2014; Herrenkohl & Polman, this volume). Technologies such as natural language processing, interactive simulations, games, collaborative tools, and personalized guidance can support students to become autonomous learners (Quintana et al., 2004; Tabak, this volume). Logs of student activities can capture class performance and inform teachers of student progress (Gerard, Matuk, McElhaney & Linn, 2015).

Autonomous learners identify gaps in arguments and independently seek evidence to select among alternatives. Learning environments can promote autonomous efforts to sort out, link, and connect cultural, social, economic and scientific ideas (see Fig. 1). Autonomous capabilities empower all citizens to take charge of their lives and strengthen democratic decision making.

This chapter integrates advances in theory, instructional design, and technology concerning interdisciplinary inquiry learning. We highlight autonomous learning from (a) student-initiated investigations of thorny, contemporary problems using modeling and computation tools, (b) design projects featuring analysis of alternatives, testing prototypes, and iteratively refining solutions in complex disciplines, and (c) reflection activities that encourage gathering and synthesizing evidence from multiple sources and using automated, personalized guidance to revise.

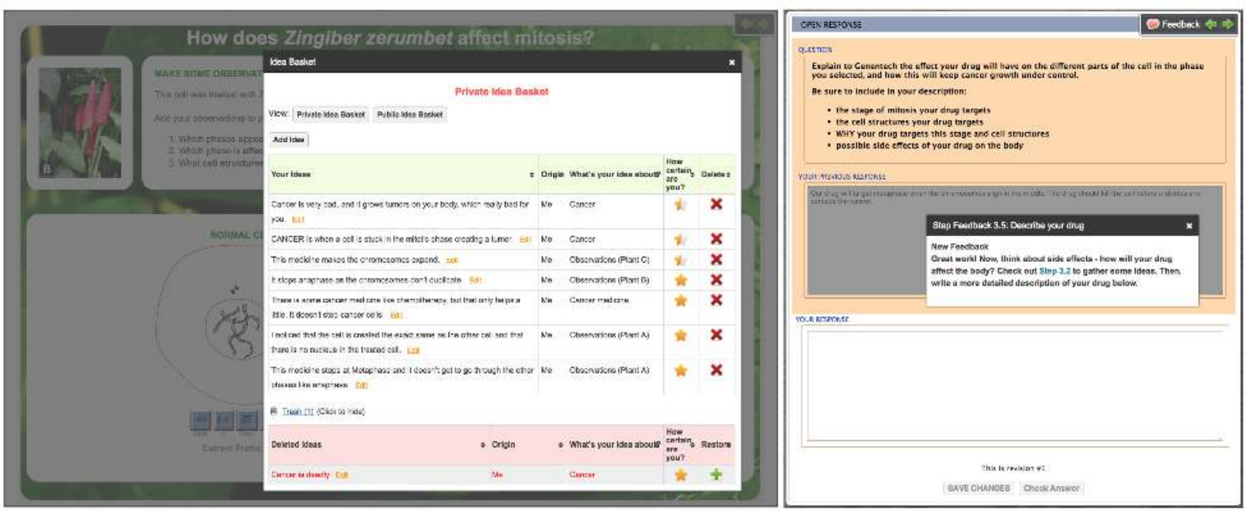

Figure 1. These screenshots from the Web-based Inquiry Science Environment (WISE) cell division unit show technologies designed to guide middle school students' inquiry into cancer treatment. The Idea Manager (left) supports students' self-monitoring and collaborative learning as they document, organize, share, and integrate their ideas (Matuk et al., 2016). Automated scoring (right) supports continuous formative assessment and personalized guidance to help students refine their arguments (Gerard et al., 2015).

Historical Trends Culminating in Impact of Learning Sciences

Inquiry instruction has roots in the experiential learning philosophies of Rousseau and Dewey. Ideals of inquiry were often inspired by images of learners, benevolently guided by a skilled tutor, independently making startling insights. For example, Rousseau (1979), describes a fictitious child who, while playing with a kite, uses the shadow of the kite to infer its position. This image of hands-on, discovery learning implies that autonomy is inherent, when it is actually cultivated through well-designed instruction. Calls for hands-on investigations or active learning tend to come from experts who are already autonomous learners. Teachers, left with the task of guiding students in inquiry, are often challenged to create the classroom structures, scaffolds for autonomous investigation, and student guidance necessary to convert hands on activities into learning opportunities.

Historically, when open-ended inquiry activities failed, they were often replaced by abstract images of the scientific method accompanied by step-by-step exercises that resonated with emerging behaviorist theories in the 1930s. For example, when students failed to derive Hooke's Law by using the scientific method to experiment with springs, designers attempted to help students identify potential confounds by providing them with explicit, step-by-step instructions. This solution made classroom implementation of experimentation easier while downplaying autonomous investigation. It also generally left students with fragmented ideas because they were not encouraged to distinguish between their own ideas and those promoted by the instruction (Linn & Eylon, 2011).

In the 1980s, spurred by government funding in Europe and the United States and building on research illustrating how scientific reasoning is entwined in and advances with disciplinary knowledge (Brown, Collins, & Duguid, 1989), disciplinary experts, learning scientists, technology experts, and classroom teachers established partnerships to improve inquiry-oriented curriculum materials and evaluate their effectiveness. For example, the US American National Science Foundation (NSF) funded individual research programs and centers that required multidisciplinary partnerships. These partnerships tackled the challenge of designing instruction that coupled inquiry about realistic, complex problems with guidance to support autonomous investigations. In addition, researchers clarified learners' autonomous inquiry capabilities as a set of interacting practices that develop in concert with disciplinary knowledge. These practices include developing and refining models, evaluating and testing simulations, analyzing and interpreting data, and forming and critiquing explanations (e.g., National Research Council, 2012).

In the 1990s, research in the learning sciences incorporated an emphasis on coherent understanding and researched autonomous learning capabilities such as metacognition and collaboration among a broad and diverse population. Furthermore, learning scientists developed learning environments that log student interactions with the goal of documenting, interpreting and supporting students' inquiry in a wide range of disciplines. In addition, designers created innovative activities that could be embedded in inquiry learning environments including concept maps, drawings, essays, hands-on examinations, critiques of experiments, and portfolios. These activities encourage students to integrate and apply the ideas they encounter in instruction while at the same time documenting student progress. Analysis of student trajectories during inquiry helps clarify how inquiry instruction can promote coherent, robust, and durable understanding of complex topics along with the autonomous capability to conduct investigations of new topics (see WISE, Figure 1).

Researchers have created culturally responsive curriculum materials featuring personally-relevant problems such as contested historical events (e.g., the Spanish-American war) or localized environmental stewardship. They have tested and refined ways to design personalized guidance, facilitate classroom discourse, help students to deal with multiple conflicting ideas, guide interpretation of historical documents, and negotiate cultural expectations. They have studied instructional patterns for guiding students to develop and articulate coherent explanations. The knowledge integration framework emerged to guide the design of learning environments, instruction, assessment, and collaborative tools with the goal of helping students express, refine and integrate their ideas to construct coherent, causal descriptions of scientific phenomena (Linn & Eylon, 2011). Constructionism, another constructivist view, emerged to guide learning from the making of artifacts (Papert, 1993). Such innovations inform design of instruction that promotes autonomy and prepare learners to use inquiry to tackle new and meaningful problems.

At the same time, the audience for inquiry learning broadened to include all citizens, not just students with professional aspirations. Learning scientists responded to this broadening of participation by incorporating identity and sociocultural learning perspectives into instruction. They began to investigate ways to develop students' identities as intentional, autonomous, lifelong learners (Raes, Schellens & De Wever, 2013). Researchers developed ways to respect and build on the diverse and culturally rich experiences students bring to inquiry activities. To address stereotypes about who can succeed in specific fields designers featured role models from the communities of the students and dilemmas relevant to their lives. The focus on relevant dilemmas has accompanied a blurring of boundaries across disciplines and between in-school and out-of-school learning. Investigators have identified ways to motivate learners to intentionally seek to make sense of the world, solve personally relevant problems, build on community knowledge, and participate in a community of learners (Danish & Gresalfi, this volume; Sharples et al., 2015; Slotta, this volume; see nQuire, Figure 2). Studies show that personalizing inquiry in the context of historical games; practical challenges such as designing low-cost e-textiles; and meaningful questions such as how to design a cancer fighting drug, can help students envision themselves as capable of solving novel, relevant challenges (Kafai, et al., 2014; Renninger, Kern & Ren, this volume).

Research methods to support investigation of the complex, systemic, and sociocultural aspects of inquiry learning have evolved with advances in the learning sciences (Hoadley, this volume). Design-based research methods that emphasize iterative refinement, informed by theory, reveal ways to improve outcomes from inquiry learning (Puntambekar, this volume; Chinn & Sandoval, this volume). Inquiry activities embedded in learning environments enable researchers to apply learning analytics to log files to reveal patterns in students' collaborative and inquiry processes (Rosé, this volume). Well-designed, technology-enhanced learning environments make it possible to utilize multiple, robust measures of student progress and implement them as part of learning rather than interrupting learning with assessments that do not themselves advance student understanding (see Pellegrino, this volume). In this chapter we discuss illustrative technological and instructional advances and identify crucial elements of successful instruction that are essential for the success of inquiry instruction and the development of autonomous learning capabilities (Linn, Gerard, Matuk & McElhaney, 2016).

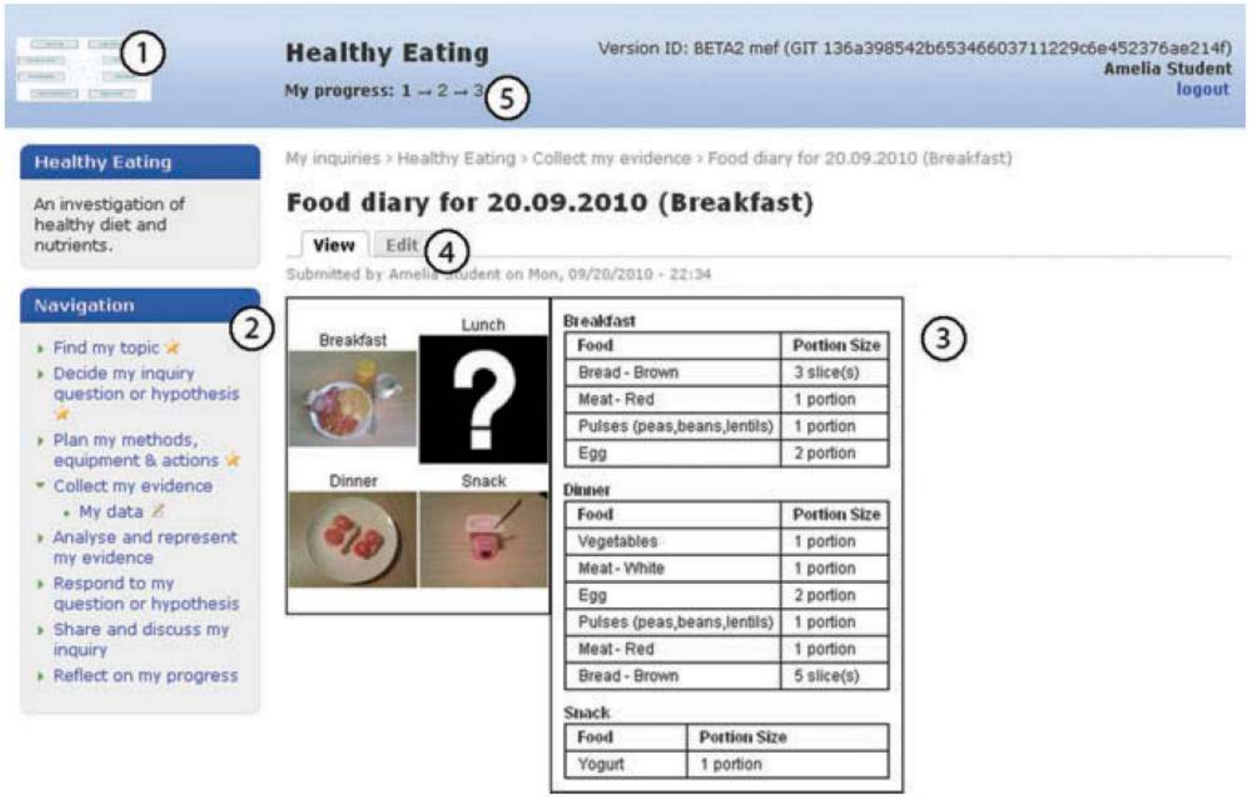

Figure 2. Screenshot of an nQuire (Sharples, et al., 2015) activity from an investigation on Healthy Eating. Numbers illustrate types of supports for learners monitoring their own progress through an investigation: (1) visual representation of the inquiry process, (2) hierarchical panel to navigate between activities, (3) current activity content, (4) tabs for toggling between activity viewing and editing, and (5) progression through temporal stages of the inquiry process.

Modeling, Computational Thinking, and Inquiry

Findings from the learning sciences have motivated educators to design instruction that makes explicit the mechanisms behind scientific and social phenomena. Models are representations (often computer-based) of a phenomenon or system whose central features are explicit and visible. The explanatory and predictive nature of models allow learners to investigate contemporary problems as part of inquiry into the natural or the designed world (de Jong, Lazonder, Pedaste, Zacharia, this volume). Technology advances (such as visualization tools, programming environments, and the computing power to handle large data sets) have made modeling a central practice in professional inquiry. Natural scientists use models to explain complex systems and to make predictions about newly observed phenomena. Engineers and designers use models to develop, and refine prototypes prior to implementing full design solutions. Social scientists use models to characterize and predict human behavior, such as outcomes of elections or sporting events.

Research syntheses of inquiry instruction that incorporates interactive modeling tools have identified design principles for promoting deep conceptual learning (McElhaney, Chang, Chiu & Linn, 2014). These studies show that effective design of instructional scaffolds contribute substantially to the value of models for promoting inquiry learning. For instance, supporting autonomous inquiry with models, rather than giving step-by-step instructions, encourages learners to test their own ideas, resulting in better conceptual or mechanistic understanding of a phenomenon. Prompts for learners to engage in self-monitoring and reflection help students achieve more coherent understanding of the phenomenon being modeled.

The emergence of computation (alongside theory and experiment) in science and engineering is promoting the inclusion of computational thinking into K-12 STEM curricular programs. By developing computational models, learners can better understand the mathematical and epistemological foundations of models and make their own decisions about what aspects of a model to include and how to specify their relationships. To meet this need, computational model building environments (such as NetLogo or AgentSheets) make the mathematical relationships that underpin complex phenomena explicit for learners (Reppening et al., 2015; Wilensky & Reisman, 2006). For example, these computational environments enable learners to simulate emergent phenomena that result from relatively straightforward rules such as the spread of disease. Computational modeling thus offers a powerful way for learners to engage in complex inquiry that integrates multiple disciplines.

A significant barrier for pre-college learners is the need for teachers and their students to learn the programming skills required to develop and test a computational model. For students to build their own artifacts or models requires more classroom time than is typically available in a science, mathematics, or history course. Learning scientists are actively exploring ways to make both model building and model exploration more accessible to all learners (Basu, et al., 2016).

Future directions: Models as assessments of inquiry learning

Students' interactions with models can provide a wealth of information with which to assess students' proficiency with inquiry practices. For example, analyses of data logs from Energy3D (Xie et al., 2014) and other modeling environments reveals learning processes that can inform the design of adaptive guidance. Many games support model-based inquiry by requiring learners to explore and understand variable relationships to achieve goals (see Fields & Kafai, this volume). Modeling activities embedded in games have the additional benefits of providing learners with continuous feedback on their completion of modeling challenges and engaging learners in a wide range of disciplines. For example, SimCity and Civilization connect a compelling narrative to underlying economic models to support causes and remedies for economic disparity (DeVane, Durga, & Squire, 2010; Nilsson & Jakobsson, 2011).

Design and Inquiry

Design is a growing part of inquiry instruction (e.g., Kolodner et al., 2003; Xie et al., 2014). Design offers realistic, ill-defined challenges through which students can apply such core practices as defining problems, making predictions, building arguments, experimentation, and iterative refinement (e.g., Blikstein, 2013). It also highlights the various facets of inquiry, including its collaborative, practical, and disciplinary natures, and its social value. For instance, in using design to address contemporary real-world problems, whether this involves designing solar ovens to replace the burning of soft coal or a campaign to promote social change, learners must develop both a deep understanding of disciplinary ideas and an ability to empathize with the people and communities for whom they design. Moreover, part of a successful design process involves reasoning about the constraints and tradeoffs of contexts and available resources; and considering and integrating diverse perspectives through collaboration and ongoing reflection.

Inquiry learning through design is valued because it goes beyond teaching content and practices to also teaching dispositions, including risk-taking, tinkering, and persistence, that foster autonomous learning. It encourages learners to pursue interest-driven projects that engage them with disciplinary ideas and practices, as in how student-driven e-textile projects can be used to introduce programming concepts to high school students and to broaden their perceptions of the role of computer science in society (Kafai et al., 2014; Fields & Kafai, this volume). Design also promotes learners' abilities to define problems, seek help, and use failure productively. Floundering while seeking creative design solutions can frustrate students, but with the proper scaffolding and guidance to surmount vexing challenges, these experiences can also be opportunities to develop self-monitoring, an aspect of autonomy (Järvelä, Hadwin & Malmberg, this volume).

Research on the potential of design activities to support inquiry learning arises from the integration of increasingly accessible fabrication technologies and constructionist learning perspectives. For instance, the increasing affordability of digital fabrication technologies has enabled a maker movement to arise, which has stimulated extensive learning activities that traverse disciplines as well as in- and out-of-school contexts (Peppler & Halverson, this volume). Recognition of the universal value of engineering practices has furthermore given rise to new engineering-related curriculum materials in pre-college education.

Future Directions: Providing Structure, Promoting Ownership

Questions remain about how to effectively guide design activities that promote disciplinary learning, while at the same time allowing learners to develop agency and pursue personal interests through taking ownership over problems. Researchers observe several successful guidelines. For instance, teachers can bring attention to productive attitudes toward risk and failure, create opportunities for learners to learn from their peers' mistakes, such as through public tests of designs, and generate authentic motivation for documenting and refining ideas (Sadler, Coyle, & Schwartz, 2000). Technology environments might empower learners with tools for creating complex artifacts, for learning productively from peers, for gaining timely access to resources, and for offering adaptive support for their design reasoning. Technology might also highlight evidence of learning from open-ended design challenges, revealing patterns that teachers can monitor and use to guide progress.

Reflection, Guidance, and Inquiry

Students gather a multitude of new ideas through modeling, design, and other inquiry experiences. However, these ideas often remain distinct from, or conflict with, one another and the ideas students have gathered from their prior experiences. Given opportunities for reflection, students can compare ideas, grapple with inconsistencies, identify gaps, and build connections among their diverse ideas. Students benefit from personalized guidance during reflection (Gerard et al., 2015; Lazonder & Harmsen, 2016).

Learning scientists have developed learning environments to guide students toward productive reflection during inquiry. They embed opportunities for students to construct arguments and explanations as they progress through an inquiry project. These activities encourage students to make their ideas visible, compare their ideas to those of their peers, and connect their ideas to prior instruction and experiences (Quintana et al., 2004). Recent technologies, including argument structuring tools and automated guidance, guide students as they sort out their often disparate views. The tools help students to refine their understanding and achieve coherent views of inquiry topics. Such technologies can also make student ideas immediately available to teachers, enabling them to help students advance their own understanding. By encouraging students to see themselves as investigators rather than accumulators of facts and to see their teachers as guides rather than authorities on knowledge, the technologies guide students to develop autonomous use of inquiry practices (Gerard et al., 2015).

Argument Structuring Tools

Refining arguments during inquiry involves the processes of critique and revision, particularly in professional practice. Studies reveal that students seldom revise their ideas. Like learners of all types, students often misconstrue contradictory evidence to align it with their view, or ignore alternative views and assert their own perspective (Berland & Reiser, 2011). Supporting argumentation in formal learning settings as a process of evidence-based revision calls for a fundamental shift in classroom culture. Rather than directing students toward the "correct" answer, argumentation emphasizes the integration of evidence and continual revision of the connections among ideas in support of coherent understanding. Students reconcile inconsistencies in their views by revisiting evidence, such as a computer model or designed artifact, and consulting resources such as peers. Learning how to use evidence and resources to construct and revise one's argument is central to becoming an autonomous learner.

Argument structuring tools enable students to distinguish and organize evidence they gather during the course of inquiry to create coherent perspectives on complex issues (e.g. using the Idea Manager, Figure 1; see Schwarz, this volume). Contemporary argument structuring tools enable students to incorporate visual evidence such as photos, screenshots, or graphs; create concept maps; and add their peers' documented ideas to their own collection of evidence. Research finds that while students identify relevant ideas during inquiry, they struggle to distinguish and integrate them. Argument structuring tools encourage students to sort their ideas into categories and refine the criteria for categories as new evidence is encountered, as steps toward forming a coherent viewpoint.

Students who categorize their ideas, as opposed to only accumulating ideas, as they progress through an investigation, form more lasting and coherent understanding of the inquiry issue. For example, students' ability to categorize the ideas they had recorded in the Idea Manager during a recycling investigation predicted the coherence of their understanding more strongly than the number of ideas they had added (McElhaney, Matuk, Miller, & Linn, 2012). Students who used Belvedere to organize their ideas were more likely to delineate connections among their ideas than students who composed solely written arguments (Toth, Suthers, & Lesgold, 2002).

Analyses of how students developed argument structures enabled learning scientists to design scaffolds that guide students to distinguish among alternatives within an argument that are likely to otherwise go unnoticed (Reiser, 2004). For example, students provided with some pre-defined conceptual categories to help them sort the evidence they gathered during an investigation were more likely to generate additional categories based on science principles, whereas students who had to generate all categories on their own were less likely to create categories to effectively distinguish among ideas (Bell & Linn, 2000). Other tools structure peer interactions to encourage students to diversify their ideas as they develop arguments. Students using the Idea Manager who added contrasting ideas from a peer to their collection of ideas, rather than adding ideas similar to their own, developed more robust arguments and science knowledge (Matuk & Linn, 2015).

Automated, Personalized Guidance for Student Explanations

Explanations, like arguments, constitute an inquiry-based artifact that compels learners to synthesize ideas from multiple sources. Providing students with guidance for their explanations can encourage students to revisit evidence and refine the connections among their ideas. This guidance is typically crafted by expert teachers, who distinguish, based on their students' explanations, the promising ideas, from those that may hinder reasoning (van Zee & Minstrell, 1997). Automated scoring technologies can support teachers in providing students with personalized guidance for their explanations during inquiry. Natural language processing tools and diagram-scoring algorithms assess the coherence and accuracy of students' explanations with scoring reliability approaching that of human scorers (Liu, Rios, Heilman, Gerard, & Linn, 2016). The resulting computer generated score can be used to provide students with immediate, personalized guidance. Even with accurate scoring, this guidance must be carefully designed in order to encourage students to make revisions that focus on connections among ideas rather than adding disparate ideas. Current research efforts examine how best to design such guidance (Gerard et al., 2015).

Research across disciplines suggests that encouraging students to critique and refine their explanations is more beneficial than providing feedback on the correctness of explanations. Comparison studies suggest that automated guidance that encourages students to distinguish and clarify the gaps in their reasoning leads to higher quality revisions during an inquiry project and higher pretest to posttest learning gains, compared to giving a specific hint or right/wrong feedback. This finding is most pronounced for students who encounter the activity with low prior knowledge, evidenced in language arts (Franzke, Kintsch, Caccamise, Johnson, & Dooley, 2005) geometry (Razzaq & Heffernan, 2009), and inquiry science (Tansomboon, Gerard, Vitale & Linn, 2017). These findings are further supported by a meta-analysis of effect sizes drawn from comparison studies of automated guidance for student generated artifacts in K-12 classrooms (Gerard et al., 2015). Guidance that provided individualized hints to help students strengthen their revision strategies, in addition to discipline specific hints, was most successful for long term learning. We conjecture this is because guidance that targets students' ideas about the discipline, as well as ideas about how to refine one's understanding, encourages students to develop the inquiry strategies essential to becoming an autonomous learner.

Future Directions: Guidance to Promote Autonomous Learning

Technological advancements coupled with learning sciences research points to the next direction: How to design guidance that promotes students' autonomous use of inquiry practices? One approach is for technology to help students form stronger connections between their everyday language and the language of the discipline. Bridging these two linguistic spheres may encourage learners to better see themselves as a participant in inquiry, leverage their existing knowledge and experiences, and subsequently develop more autonomous use of inquiry practices. For example, situating reflection activities in students' natural activities such as a peer dialogue could elicit and capture students' articulation of inquiry issues in their everyday language. Natural language processing can be used on this data set to identify students' expressions, and this language can be used to tailor guidance.

Another promising direction is using automated analysis of students' reflections to provide teachers and school leaders with rich assessment information. This approach converts meaningful learning activities such as student written or diagrammed arguments, into powerful assessments. Using both written and diagrammatic assessments increases scoring validity and provides language learners an alternative method to express their views (Ryoo & Linn, 2015). Drawing on embedded data provides stakeholders with data on student trajectories, as opposed to student performance at a fixed timepoint. This focuses assessment on both learners' disciplinary understanding and their use of inquiry practices to refine their views.

Conclusions

Inquiry skills can promote lifelong learning and active participation in society. Researchers are exploiting new technologies to broaden the scope of inquiry, enable teachers to localize instruction, and help students develop autonomous learning capabilities that are essential for addressing contemporary issues, thereby improving their own and others' lives.

Promoting autonomy

Preparing learners to address complex problems through inquiry requires carefully designed curriculum materials that take advantage of innovative learning technologies while also building on learners' ideas. Research has found promise in various technologies for supporting students in generating and testing their own ideas by guiding them in developing models, designing solutions, and constructing evidence-based explanations. These technologies prompt students to continually monitor their progress and evaluate and refine their own inquiry artifacts. Personalized guidance based on automated analysis of logged data can encourage learners to assume greater responsibility for their own progress, rather than view their teacher as the singular authority on knowledge. These technologies show promise in supporting inquiry across disciplines, including language arts, history, science, mathematics, engineering, and economics.

Inquiry-based materials can emphasize issues that students will find relevant at the individual, community, and/or global levels. Selecting relevant contexts can engage diverse students, and promote their agency and identities as inquiring citizens. Inquiry curricula that also highlight connections among historical, social, scientific, and mathematical domains; and make connections to out-of-school learning opportunities can reveal the connections between classroom learning and everyday life (see Lyons, this volume).

Opportunities for Continuous Assessment

Technology-enhanced inquiry instruction provides opportunities to reconceptualize assessment as a continuous, formative process integrated with instruction instead of a summative, standardized process sequestered from instruction. Continuous assessment offers students more varied and authentic ways to express their ideas than typical summative assessments. Technology-enhanced learning environments can take advantage of learning analytics approaches to measure student trajectories during the course of instruction. Coupling these embedded assessments with guidance tightly integrates instruction and assessment and promotes students' self-monitoring, self-evaluation, and iterative refinement that are central to autonomous inquiry learning.

Technology-enhanced environments, whether investigation-based or game-based, can use data logs to make student progress visible to teachers. Dashboards of student learning can inform teachers' individual or whole class guidance. These reports not only represent learning at a particular point in time, but also provide valuable information about students' learning trajectories over time.

Synthesis of Technological Innovation

To promote more efficient, collaborative progress, the NSF Task Force on Cyberlearning (2008) encouraged researchers to build on, rather than reinvent existing solutions. A learning environment (e.g., Fig. 1 & 2) open to all designers and users could support such efforts, and dramatically accelerate both research on and scalability of inquiry learning. It would offer instructors a repository of tested and refined curriculum materials, and could readily evolve to incorporate emerging technologies such as automated scoring, computational modeling tools, collaborative features, and games (ISLS, 2016a,b,c).

Such an environment could support comparative research on the diverse theoretical perspectives and contexts currently used, and help to synthesize our collective understanding of ways to support inquiry learning (e.g., how to balance the quality and amount of guidance for developing autonomous inquiry skills). It could also provide continuous assessment of learners' progress within and across their learning experiences. Information from such assessments could be used to tailor instruction to individuals based on their past experiences in multiple disciplines. Guidance could build on student insights from prior instruction and related courses, ensuring that each learner is appropriately challenged.

Finally, this environment could provide a common platform for teachers to seamlessly implement series of inquiry activities, collaborate on customizing materials, share strategies for enactment, and collaborate with researchers to create and test new learning innovations.

Annotated References

Furtak, et al, (2012)

This meta-analysis synthesizes 37 studies of inquiry published between 1996 and 2006. Consistent with prior research, the mean effect size was .50 favoring inquiry. The effect size for studies featuring teacher-led inquiry was .40 higher than the effect size for student-led inquiry. These results underscore the importance of guidance to realize the benefit of inquiry instruction.

McElhaney et al. (2014)

This meta-analysis synthesizes 76 empirical design comparison studies testing the effectiveness of instructional scaffolds for modeling tools in science. Each of the 76 studies isolates a single design feature of the tool (or the supporting instruction for the tool) by comparing learning outcomes from a typical version of the tool to an enhanced version. Inquiry-based scaffolds found to be most successful include interactive modeling features and prompts for promoting sense-making, self-monitoring, and reflection.

Gerard et al. (2015)

This meta-analysis synthesized 24 independent comparisons between automated adaptive guidance and guidance provided during typical teacher-led instruction, and 29 comparisons between enhanced adaptive guidance and simple adaptive guidance. Adaptive guidance demonstrated a significant advantage over each of the activities used by the researchers to represent "typical classroom instruction." Enhanced guidance that diagnosed content gaps and encouraged autonomy was more likely to improve learning outcomes than guidance that only addressed content.

Raes et al. (2013)

This experimental study investigates the impact of a web-based, collaborative inquiry unit on diverse high school students in 19 classes. The results show that inquiry is effective and has advantages for students who are not typically successful in science or are not enrolled in a science-track. Furthermore, the unit gives low-achieving students and general-track students an opportunity to develop science practices and confidence in learning science.

Xie et al (2014).

This study describes the use of a computer-aided design environment for assessing students' engineering design processes. Students' interactions with the environment are continuously logged while students engage with a design challenge. A classroom study examined the logs of high school engineering students work on a solar urban design challenge.

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