The Design Implementation Framework:
Iterative Design from the Lab to the Classroom

Melissa L. Stone
Arizona State University, United States
Kevin M. Kent
Arizona State University, United States
Rod D. Roscoe
Arizona State University, United States
Kathleen M. Corley
Arizona State University, United States
Laura K. Allen
Arizona State University, United States
Danielle S. McNamara
Arizona State University, United States

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Arizona State University, United States

ABSTRACT

This chapter explores three broad principles of user-centered design methodologies: participatory design, iteration, and usability considerations. The authors highlight the importance of considering teachers as a prominent type of ITS end user, by describing the barriers teachers face as users and their role in educational technology design. To exemplify these points, they draw upon their experiences in developing the Writing Pal—an ITS for writing strategy instruction. The chapter concludes by offering a design approach—the Design Implementation Framework (DIF)—that builds upon existing cyclical design methods but is tailored to the design of ITSs and other educational technologies.

Keywords: Design-Based Implementation Research, Design-Implementation Research, Instructional Systems Design, Intelligent Tutoring Systems, Participatory Design, Research Partnerships, Writing Pal

INTRODUCTION

With each new school year, the list of available educational technologies expands dramatically, along with more widespread integration of these technologies into classrooms. Educators at all levels increasingly rely on a variety of technologies to engage students in learning complex material across domains. These technologies vary in form and function, such as assistive technologies (e.g., text-to-speech software and interactive whiteboards) that facilitate or transform teaching, and instructive technologies that directly teach concepts, train skills, scaffold practice, and provide feedback. Across these formats, however, educational technologies are beholden to similar questions and constraints regarding design, usability, and implementation. *How can these tools be developed and deployed in ways that consider teachers' and learners' true needs in school environments?*

One widely used type of educational technology is the intelligent tutoring system (ITS). Briefly, ITSs are computer programs that model expert human tutors by instructing students on a specific topic or skill, providing feedback on responses, and strategically facilitating student performance and understanding through adaptive instruction (Anderson, Boyle & Reiser, 1985; Burns, Luckhardt, Parlett & Redfield, 2014; VanLehn, 2006). One-on-one human tutoring has been shown to be a highly effective mode of instruction; however, it is severely limited by the availability of expert human tutors (Muldner, Lam, & Chi, 2014). ITSs have been developed in response to this problem. These systems rely on artificial intelligence-based computer systems and agents to provide students with personalized educational experiences that model human tutoring.

By various measures, these efforts have been successful. For example, Ma, Adesope, Nesbit, and Liu, (2014) conducted a meta-analysis of effect sizes from 107 ITS studies that incorporated 14,321 participants from K-12 and college populations and spanned eight different content domains. The study found that, across various uses (i.e., the primary means driving instruction, a supplement to instruction, a component of instruction, and an aid to homework), ITSs were associated with superior performance in comparison to large-group instruction (g = 0.42), non-ITS computer-based instruction (g = 0.57) and instruction via textbooks (g = 0.35). Importantly, the meta-analysis revealed no significant differences when comparing ITS use to human tutoring or small-group instruction. This finding provides support for a previous review (VanLehn, 2011), which showed that ITSs provided nearly the same learning gains in STEM topics as one-on-one human tutors. Support for the effectiveness of these systems has been replicated in studies across a variety of domains, such as in K-12 pupils' mathematical learning (Steenbergen-Hu & Cooper, 2013), and physics and computer literacy (Nye, Graesser & Hu, 2014). These positive findings have spurred the popularity of ITSs in classrooms, as these systems continue to influence the educational landscape.

Surprisingly, despite the popularity and effectiveness of these systems (and perhaps *because* they appear to work so well), there has been little research published on their design, usability, or user experiences (Chughtai, Zhang, & Craig, 2015; Lin, Chen, Sun, & Tsai, 2014; Lin, Wu, & Hsueh, 2014; Sung & Mayer, 2012). Both early and current research on ITSs has been driven primarily by considerations related to learning processes and performance gains. Exemplar questions include: *How do people learn math?*, *How should people learn how to write?*, and *What pedagogical approaches are most effective?* Answers to these questions help with the development of instructional design principles such as "give hints, but not too many" and "teach explicit metacognitive strategies." Such an approach is necessary and useful in guiding the development of systems that help students learn. However, design principles derived from the learning sciences are potentially separable from those that emerge from a focus on usability and user experience. Although innovative instructional ITS elements such as animated pedagogical agents (Kim & Baylor, 2016), natural language interaction (Graesser, Li, & Forsyth, 2014), and affect-aware scaffolding (D'Mello & Graesser, 2015) can be effective, they are certainly influenced by good interface, navigation, and aesthetic design (e.g., clear and organized menus). Likewise, effectiveness may depend upon users' impressions and subjective reactions to these features (Mayer & Estrella, 2014; Roscoe, Wilson, Johnson, & Mayra, 2017).

While ITS developers have often reported target users' enjoyment and ease of use (e.g., Jackson & McNamara, 2013; Sung & Mayer, 2012), there are few focused usability studies in the literature (Chughtai, Zhang, & Craig, 2015), and developers have largely ignored usability from the point of view of the instructor or teacher. In this chapter, the authors argue for the importance of user-centered design, particularly with teachers, at all stages of the ITS life cycle. The first section summarizes key principles or commitments of user-centered design. Next, characteristics of teachers as an important type of ITS end user, including barriers teachers face as users and their role in educational technology design are discussed. To exemplify key points, the authors draw upon their experiences in developing an ITS for writing strategies (i.e., the Writing Pal). Finally, the last section describes a design approach—the Design Implementation Framework (DIF)—that builds upon existing cyclical design methods but is tailored specifically to ITS and educational technology contexts.

USER-CENTERED DESIGN AND EDUCATIONAL TECHNOLOGY

Broadly, user-centered design refers to a set of "design processes in which end-users influence how a design takes shape" (Abras, Maloney-Krichmar, & Preece, 2004; see also, Brhel, Meth, Maedche, & Werder, 2015; Lowdermilk, 2013). The purpose of user-centered design is to create products, tools, software, and systems that are attuned to the needs, goals, and limitations of the intended users. To achieve these goals, user-centered design emphasizes the importance of end-user input at *all stages of development*. Although usability and user experience problems are virtually guaranteed in any product or software system (e.g., Albert & Tullis, 2013), such issues have not been a focus of published research on ITSs. When end-user considerations are collected, it is usually done so via "feedback surveys" or post-hoc analyses embedded within evaluation studies of ITSs (e.g., Pane, Griffin, McCaffrey, & Karam, 2014). In simple terms, studies designed to test the question: *Did students learn?* sometimes also investigate: *Did students like it?* Satisfaction is certainly one aspect of usability (Nielsen, 2001), but evaluating a singular aspect of user experience very late in the development cycle neglects the true potential of user-centered design approaches.

Drawing on the extensive literature on design, the authors emphasize three core principles that could be used to drive research and discussion of educational technologies: *participatory design*, *iterative design*, and *usability considerations* (e.g., Banathy, 1987; Brandt, 2006; Danbjorg, Clemensen & Rothmann, 2016; Gagne, 1987; Fishman, Penuel, Allen, Cheng & Sabelli, 2013; Kensing & Blomberg, 1998; Lebow, 1993; Molenda, 2003). Teachers as a specific class of end users that are important to ITS development is then discussed.

User-Centered Principle 1: Participatory Design

Participatory design actively engages prospective and authentic end users in a dialogue with designers during the development of a product (Bravo, 1993; Muller, 2003; Könings, Seidel, Jeroen, & van Merriënboer, 2014; Khaled, & Vasalou, 2014). In short, users are invited to "co-develop" the product as respected decision-makers rather than mere suggestion-makers (Bravo, 1993). This approach is already widely used in a variety of fields including software design, urban design, product design, graphic design, sustainability, labor studies, political science, and architecture (Muller, 2003). In educational technology development, researchers who engage in participatory design commit to active partnerships with participants—particularly teachers—to ensure that products meet real-world needs and are usable by a variety of learners. Additionally, teachers participate in developmental decisions regarding instructional goals, content, features, and design, and then continue to address issues that arise in the instructional design, usability, and implementation of the product (Greenbaum, 1993).

An existing framework that emphasizes participatory design is Design-Based Implementation Research (DBIR; Fishman, Penuel, Allen, Cheng & Sabelli, 2013), which seeks to connect researchers and practitioners in systematic inquiry, iteration, and collaboration. An important DBIR principle is "deciding on focus for joint work." Development teams are formed to explicitly represent multiple perspectives (e.g., teachers, students, district leaders, researchers, community members) to define and achieve common goals, identify problems, and negotiate solutions. DBIR emphasizes participatory design that is grounded in and responsive to local circumstances. This approach has resulted in improved technology implementation and integration in projects, such as the development of a high school mathematics curriculum (Johnson, Severance, Leary, & Miller, 2014) and a middle school formative science assessment (Penuel & DeBarger, in press).

User-Centered Principle 2: Iterative Design

Iterative design is the cyclical process of designing, gathering feedback, and improving initial designs over a relatively short timescale (Endsley & Jones, 2011). Rather than substantial "capstone" or "efficacy" oriented research studies, iterative design emphasizes fast and efficient cycles of ideation, finding problems, and fixing problems. Moreover, these iterations occur throughout the lifecycle of a technology (Fox, Sillito, & Maurer, 2008). During initial ideation, plans may be rapidly brainstormed and tweaked before a single prototype is crafted. Similarly, prototypes and evolving versions of the system can be continuously probed and tested. Even once complete products are generated and deployed in the marketplace (or classrooms), feedback can be collected and used to guide later redesigns.

This continuous, iterative approach is a hallmark of Instructional Systems Design (ISD) approaches that are commonly used to design training, education, and development programs (Banathy, 1987; Gagne, 1987). ISD broadly aims to define the state and needs of the learner, determine goals of instruction, and create sustainable implementation (Lebow, 1993). For instance, the ADDIE model recommends a cycle of analysis, design, development, implementation, and evaluation (Gibbons, Boling, & Smith, 2014; Molenda, 2003). Long before a system is built or deployed in a given context, developers must clarify instructional problems, define learning objectives, and identify the content that will need to be integrated into the technology. Design and development activities then produce and test prototypes that ultimately lead to functional systems that are implemented in classrooms or other educational settings. Evaluative activities then measure the efficacy of the technology compared to the original objectives of the project. Importantly, evaluative activities can and should play a role other in stages of development. For example, in the early stages of a project, researchers can use the information from a needs assessment to mockup designs and then continue to solicit feedback and improve usability as the product matures.

Another key feature of iterative design is the constant elicitation of user feedback throughout the life cycle of a product. During initial design, different types of system plans and modifications may be made in response to user-reported issues or suggestions. Feedback during the latter stages of implementation and evaluation can trigger a shift back in the design stage (i.e., “back to the drawing board”) to address major issues (Molenda, 2003).

User-Centered Principle 3: Usability Considerations

Developers of ITSs must balance considerations related to function and form as they craft products that are both useful and easy to use. According to Nielsen (1993; see also, Madan & Dubey, 2012), usability can be conceptualized along five dimensions: *learnability*, *efficiency*, *memorability*, *errors*, and *satisfaction*. Users must be able to learn how to use the system (not the same as “learnability” of the subject matter), and should be able complete desired tasks smoothly, with minimal wasteful actions and mistakes. All of these factors combine to influence user satisfaction—systems that are awkward to use, error-prone, and confusing are unpleasant and unusable.

In educational technology, usability includes the ability of the users (i.e., learners or teachers) to concentrate on learning and teaching the content rather than navigating the software or website. As mentioned previously, educational technologies are usually carefully built to enact research-based methods of teaching and learning. Naturally, researchers want teachers and students to fully engage with these cutting-edge features without distraction or frustration stemming from poor usability. Incorporating teacher and student input throughout design helps to identify violations of the aforementioned principles. As a result, teacher participation during development should yield more efficient, user-centered results that enable success and side-step avoidable problems (Danbjorg, Clemensen & Rothmann, 2016).

TEACHERS AS KEY USERS OF EDUCATIONAL TECHNOLOGY

The three principles outlined above represent a non-exhaustive set of factors to consider in work on ITS development. Embedded in all of the principles is a focus on users—the individuals and organizations that will use the ITS to instruct and learn. Of course, students are one class of important end users because robust student learning is a focal outcome. However, as ITSs continue their spread and integration in thousands of classrooms, *teachers* are also critical users who serve as gatekeepers, evaluators, and decision makers for ITS implementation. Thus, the authors propose that teachers represent an essential class of ITS users who need to be included in user-centered design work and research (Heffernan & Heffernan, 2014; Holden & Rada, 2011; Könings, Seidel, Jeroen, & van Merriënboer 2014). Teachers must be represented in iterative and participatory design activities and researchers must consider usability and context with teachers’ unique constraints and needs in mind.

Teachers as Users

To effectively and conscientiously engage teachers in development and design, an understanding of their unique roles and characteristics is necessary (i.e., an aspect of needs assessment). In classroom implementation of educational technologies, teachers make fundamental decisions about how and whether to incorporate technology into their lesson plans, which in turn affects how students use and benefit from the technologies. Involved in these decisions is an understanding of when, where, and how the technologies are best used. When systems track student proficiency, skills, and performance, teachers need to interpret these data and choose how to tailor future assignments and lessons.

A number of researchers have sought to identify and discuss common challenges regarding teachers and technology (e.g., Ertmer, 1999; Inan & Lowther, 2009; Johnson, Jacovina, Jackson, Tighe & McNamara, 2016; Mishra & Koehler, 2006). The majority of these challenges can be categorized as either first or second order barriers (Ertmer, 1999). First order barriers are external to the teacher, including lack of access to and reliability of resources, training, and support. Second order barriers include teachers' own attitudes and beliefs, resistance to using technology, and lack of confidence in their skills and knowledge. These factors play a crucial role in implementation effectiveness in the classroom. Teacher beliefs can impede technology integration by constraining instructional design decisions and pedagogical approaches (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Kim, Kim, Lee, Spector, & DeMeester, 2013; Polly et al., 2013).

For instance, teachers who believe that students learn by actively building understanding, rather than passively absorbing information (see Chi, 2009; McNamara, Jacovina, & Allen, 2015), are more likely to use technology for high-level activities, such as problem solving and application, as opposed to lower-level activities such as rote practice (Becker, 1994; Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Hadley & Sheingold, 1993). Additionally, other research has found that teacher beliefs about classroom discussion is related to the sophistication of their technology use, where teachers who believed that discussions should more be open-ended were more likely to use technology in innovative ways (Kim, Kim, Lee, Spector & DeMeester, 2013). A research-based path model was developed by Inan and Lowther (2009) in an effort to articulate multiple dimensions of variables affecting technology integration. The model includes several external factors (e.g., number of years as a teacher, age of participants, support from the school community, technical support, availability of computers), as well as internal factors (e.g., teachers' beliefs and readiness, perception of computer skill level). An analysis of these variables revealed that teachers' readiness, beliefs, and computer availability were significantly related to their integration of technology, with feelings of readiness having the strongest relationship. Additionally, there was a negative relationship between years of experience teaching and readiness to integrate technology, whereas teacher age was not related to feelings of readiness. From these findings, it is clear that teacher knowledge, beliefs, and skills are related to technology adoption and the role that technology plays in the classroom (Ertmer, 1999; Hermans, Tondeur, van Braak, & Valcke, 2008; Mishra & Koehler, 2006). Accordingly, to improve technology design, teachers should have a voice in the research process.

Teachers and Participatory Design

Involving teachers in the development and improvement of educational technologies offers clear benefits (Oh & Reeves, 2010; Sugar, 2002). In design research, for example, researchers and practitioners explore problems collaboratively to discover practical solutions and theory in design and learning (Brown, 1992; Collins, 1992, Nieveen, McKenney & van den Akker, 2006). One such case is offered by researchers developing a Multi-User Virtual Environment (MUVE) called River City (Dede, Nelson, Ketelhut, Clarke, & Bowman, 2004; Ketelhut, Clarke, & Nelson, 2010). River City was designed to support students' science inquiry skills and understanding of cause and effect in ecosystems. The research team piloted the system in the classroom and both student and teacher feedback were collected. Teachers were given surveys about their perceptions of the system and prior experience with classroom technology. The results showed that although teachers were open to student-centered approaches to instruction, teachers needed more support implementing River City in their classroom. The research team responded to this concern by creating an 8-hour professional development session.

Teacher involvement in the design process has also been shown to be beneficial to their knowledge and skills surrounding technology implementation. For instance, in a study by Koehler and Mishra (2005) college faculty members and graduate students co-designed an online course over the length of a semester. The researchers were interested in whether this experience was beneficial to both faculty members and students in improving their knowledge surrounding technology implementation. Using the TPCK framework (Technological Pedagogical Content Knowledge; Mishra & Koehler, 2006), the researchers found significant improvements in the participants' understanding of the dynamics of technology use in the classroom. Another study showed similar benefits for teacher self-efficacy when teachers created video games to help students learn difficult science concepts, particularly for teachers with technology experience (Annetta et al., 2013).

In sum, prior work in educational technology design suggests that involving teachers in the design process is a valuable and potentially necessary aspect of successful development. Moreover, participating in design may help teachers improve their knowledge and skills around technology use, potentially overcoming knowledge and confidence barriers to implementation.

PARTICIPATORY DESIGN WITH TEACHERS AND WRITING PAL

Over the past decade, the authors' laboratory (soletlab.com) has developed and refined the Writing Pal (W-Pal), a web-based ITS that aims to improve student essay writing (e.g., Dai, Raine, Roscoe, Cai, & McNamara, 2010; McNamara et al., 2012; Roscoe, Allen, Weston, Crossley, & McNamara, 2014; Roscoe & McNamara, 2013). Various studies (both published and unpublished) with W-Pal can be used to highlight the impact of user-centered design with teachers as ITS users.

Overview of Writing Pal

W-Pal is organized around a series of eight learning modules that explain and demonstrate writing strategies for planning (*Freewriting* and *Planning*), drafting (*Introduction Building*, *Body Building*, and *Conclusion Building*), and revising (*Paraphrasing*, *Cohesion Building*, and *Revising*) argumentative essays. Each module comprises several animated lessons that teach the strategies along with one or more mini-games that enable practice of those strategies. For instance, *Fix It* is a game in which students must identify and repair errors in an introduction, body, or conclusion paragraph (e.g., an omitted thesis or topic statement). By correctly identifying and fixing the text, students earn "golden circuit" pieces they can use to solve a Sudoku-like puzzle. Other games are generative and ask students to author new text. For example, in *Freewrite Flash*, students engage in idea generation via freewriting. Students earn points for quickly generating more and diverse ideas in a short span of time.

Figure 1. Fix It Introduction Building Game

W-Pal also includes an automated writing evaluation component that allows students to compose complete essays and receive automated scores and formative feedback. W-Pal currently focuses on argumentative writing using pre-generated prompts similar to those encountered in standardized exams; however, teachers can also customize W-Pal by creating their own writing prompts. After students write and submit an essay, they receive automated summative (holistic score from 1-6) and formative feedback that is driven by a series of natural language processing algorithms. This feedback is aligned to the writing strategies taught in the videos, and considers a broad range of linguistic, rhetorical, and contextual features (McNamara, Crossley, & Roscoe, 2013).

Finally, W-Pal supports classroom implementation in multiple ways. First, as noted above, teachers can create and customize their own writing prompts. Second, teachers can use system and custom prompts to assign essays, with options to include due dates, turn off the essay timer function, and allow for revisions.

Third, teachers can comprehensively monitor students' performance and progress. Tabs and spreadsheets in the teacher interface summarize student performance and progress for lesson videos, scores and attempts for each strategy practice game, and the scores and feedback received on every essay submitted.

Prior empirical studies have demonstrated the benefits of Writing Pal for writing quality, strategy acquisition, and motivational engagement (e.g., Allen, Crossley, Snow, & McNamara, 2014; Roscoe, Brandon, Snow, & McNamara, 2013; Roscoe & McNamara, 2013). In addition, the researchers' mixed-method research has explicitly addressed usability and user experience concerns in both lab and school-based research (Johnson, Jacovina, Jackson, Tighe & McNamara, 2016; Roscoe, Allen, Weston, Crossley, & McNamara, 2014; Roscoe & McNamara, 2013; Roscoe et al., 2011). Studies have included surveys to measure perceptions, attitudes, motivation, and trust, and have also used log-file data to examine users' behaviors and choices (Allen et al., 2016; Snow, Allen, Jacovina & McNamara, 2015). Pilot implementation studies in classrooms have also been conducted to fine-tune problem areas or help inform major adjustments. Across many of these efforts, participatory design and contributions from teachers have been essential.

In the following sections, the authors discuss three aspects of user-centered design and participation activities over the lifecycle of W-Pal. These examples (and others) have informed—and continue to inform—the design and redesign of the system: early development of W-Pal content and pedagogy, later development and refinement of the W-Pal system, and forming and sustaining teacher partnerships.

Teachers and Early Development

From the earliest stages of W-Pal development—determining the instructional objectives, content, and scope that should be included in the system—user-centered design approaches have been implemented, often with teacher input (e.g., Kim et al., 2012; Roscoe, Allen, Weston, Crossley, & McNamara, 2014). Specifically, the strategy-based lesson videos were initially planned and developed via focus groups with teachers, and refined through subsequent usability and feasibility testing.

In focus group sessions, Kim and colleagues (2012, see also Roscoe et al., 2014) invited high school teachers from Memphis, TN (n = 8) and the Washington, DC area (n = 6) to discuss essential goals and strategies for writing pedagogy. Participating teachers were informed that researchers were creating a new tutoring system for writing, and that their input was necessary to determine the topics that would be covered. These conversations revealed the need to cover all aspects of the writing process (i.e., planning, drafting, *and* revising) and to enable writing practice along with strategy instruction. During these sessions, teachers also recommended the use of interactive games in W-Pal to promote student engagement. Thus, these findings informed the research team's creation of lessons and games that reflected the knowledge and values of the expert teachers.

The participation of teachers did not cease after their initial input. For example, once a complete "version 1" of the system had been developed, a feasibility study was conducted over the span of an entire school year in several Washington, DC area English classrooms (Roscoe et al., 2014). Two teachers implemented W-Pal to provide strategy instruction, game-based practice, and writing practice, and also generated their own writing prompts. Importantly, the participating teachers were interviewed by the research team several times per month over the school year. These sessions revealed several key usability issues. For example, version 1 lesson videos were too long—although the information was useful, it was "too much" all at once. Moreover, the use of multiple animated characters resulted in distraction that obscured the lesson content. Consequently, from this feedback emerged the current design of short, animated lessons featuring a single character discussing a focused topic. Instead of eight lengthy videos (i.e., one per module), W-Pal now offers almost 40 videos of just 3-5 minutes in duration. Another example pertains to the mini-games. Teachers and students found the games to be engaging (e.g., Roscoe, Brandon, Snow & McNamara, 2013), but recommended more challenging generative games that allowed students to author new text. In response, researchers redesigned or created more games to provide students with these needed opportunities. Other improvements included the addition of “printing” and “exporting” functions in the teacher interface and rewording of the formative feedback to be more grade-level appropriate.

In sum, the overall quality of W-Pal benefited from teacher input and participation from pre-prototype stages through to the realization of a complete version.

Teachers and Later Development

W-Pal has now existed as a fully-featured and effective writing ITS for a number of years, yet (re)design and (re)development necessarily continues—no system is ever “finished.” Throughout these later stages, teacher input has remained crucial in revealing problems and improving features. Each new teacher contributes new insights and observations that can lead to revisions and improvements.

The W-Pal developers have continued to conduct focus groups with teachers to assess perceptions of system features and interface design. Questions posed to teachers query their overall impressions of W-Pal as well as their beliefs and attitudes regarding learning and technology. For example, questions in these sessions have included: *How would your students/colleagues react to W-Pal?*, *What would you like to see in terms of data and visualization to help you make instructional decisions as a teacher?*, *What information would you want for grading and assessing student progress?,* and *What kind of support would be helpful in implementing a technology like W-Pal?* In one session, teachers (n = 10) provided a practitioner’s perspective regarding the use of student performance data collected by W-Pal to guide classroom instruction *outside* of W-Pal. That is, focus group participants conceptualized W-Pal as a tool that could be integrated into classroom instruction rather than an ancillary tool that students merely use at home for extra practice. For instance, teachers expressed a desire to obtain performance data on their students’ specific writing skills (e.g., thesis writing). These performance data, they argued, could empower them to better differentiate instruction for individual learners. Focus group members also stressed the value of reviewing evidence of skill progression over time for both individual students and class-level aggregates. Teachers also envisioned using data collected in W-Pal to inform student portfolios and reports to share with parents and guardians during conferences.

Another approach that the W-Pal developers have found particularly useful is to take on the role of the teacher (i.e., user) themselves (similar to developers taking on role of a student attempting to revise, Roscoe et al., 2011). Recently, W-Pal was implemented within a college freshman course taught by a few members of the development team. Interestingly, issues that had seemed minor (and had not been reported by teacher users), were magnified in the context of actually using the system in a classroom. In contrast to the teachers, the experimenters had a sense of the system *should* do or *could* do. In particular, the instructors encountered several limitations in the teacher interface that rendered it unnecessarily challenging to access the student data used for grading. The instructors were also frustrated while using the student progress, assignment, and classroom setup features. In one case, student completion dates were obscured in the teacher interface such that the task of tracking time-based student work became challenging. In another instance, students in the class misinterpreted weekly assignments, sometimes completing the wrong tasks or missing them altogether. Hence, the instructors were forced to abandon the automated notification system, and provided instructions to the students themselves.

As a function of these recent focus groups and the developer-led classroom implementation, key challenges were revealed and are currently being addressed. A significant overhaul of the teacher interface is underway to improve navigation, aesthetics, and clarity. The research team is also working to create new feature designs for the teacher interface and test the designs in laboratory usability sessions.

Collaborative Research Partnerships

Given the importance of teacher participation in design, development, and testing, it is crucial to form and nurture productive partnerships with teachers and schools. Teacher interviews and observations have revealed found that teachers who feel “distant” from the research process are less likely to use W-Pal during the school year. In contrast, and in accord with DBIR and participatory design principles (e.g., Fishman, Penuel, Allen, Cheng, & Sabelli, 2013), teachers who perceived a more active role in the research process were more active users. Thus, implementation with "teachers as users" should evolve into collaboration with "teachers as partners." Collaborative partnerships encourage teacher and student participation in research questions, support modifying instructional tools in ways that are responsive to local circumstances, and reveal new contexts for translation and long-term benefits of implementation.

Sustaining these partnerships is not easy—researchers must avoid unidirectional and unbalanced stakeholder relationships (Goos, 2104; Houseal, Abd-El-Khalick, & Destefano, 2014) by providing value for the schools beyond "giving them the technology." Following Fishman and colleagues (2013), who consider the development of institutional capacity a necessity for the successful implementation and extended use of an educational technology, the W-Pal team has created six hours of professional development (PD) for teachers. Designed to support sustained W-Pal implementation in schools, the PD includes an introduction to:

- The W-Pal System
- The cognitive science of teaching and learning
- Classroom technology integration

The PD session is structured around generative topics, as recommended in the Teaching for Understanding framework for designing instruction and curricula to promote inquiry and engagement (Wiske, 1998, Darling-Hammond et al., 2015). Each topic is intended to promote conversation regarding fundamental questions about teaching with technology. For example, Part Two of the session asks: *How can technology integration be additive to teaching and learning?* This PD session seeks to help teachers become more skillful, confident, and independent when implementing W-Pal in their classrooms without the direct facilitation of the research team. To support teacher learning, the session introduces TPCK and features a brainstorming activity where teachers are given an example from two of the three TPCK elements (technology, content, and pedagogy) and are asked to generate an example of the third element that could fit the other two examples (Hervey, 2013). Once the teachers have cycled through a few rounds of the game, they are asked to engage in a similar activity with Writing Pal. Another objective is to discuss the underlying instructional goals and principles of the system, thus establishing a participatory relationship that invites usability and user experience feedback throughout use of the system.

In sum, although collaborative research partnerships are not specifically a design method or form of usability assessment, they affirm teachers' role in such efforts. By creating and nurturing collaboration, researchers gain more honest, thorough, and enthusiastic participatory design input from teachers.

THE DESIGN IMPLEMENTATION FRAMEWORK (DIF)

The preceding sections have outlined broad user-centered design principles (e.g., iterative, participatory design) and touched upon the ways in which these principles have been enacted in W-Pal development. The authors have further emphasized the special role of teachers as end users in such research. Both empirically and anecdotally, these user-centered efforts have made W-Pal a more "user friendly" and effective tool for teaching writing.

To conclude the chapter, key concepts are summarized within a tentative framework that other ITS and educational technology researchers may find helpful for conducting (and publishing) usability and user experience research. This approach—the Design Implementation Framework (DIF)—describes phase transitions through problem encounters, design, laboratory studies, feedback collection, and subsequent implementation. The DIF is rooted in existing design models like DBIR (Fishman, Penuel, Allen, Cheng & Sabelli, 2013) and ADDIE (Molenda, 2003), which are functional and well established.

The DIF identifies five phases in the design and development of system features. As shown in Table 1, the model consists of five stages that will be explained in the sections that follow.

Table 1. Phases and Definitions of the Design Implementation Framework

DIF Phase	Definition
Defining and Evaluating the Problem	The act of identifying one or more central research questions or problems related to educational technology. These questions and needs can emerge from the developers' instructional or theoretical goals.
Ideation	A creative and collaborative brainstorming process through which researchers and developers of an educational technology come up with a variety of plans for implementation or further investigation.
Design and User Experience	Rather than immediately reprogramming the "live" system back-end, interfaces, or other features, usability and user experience research methods can test and refine the designs (e.g., through sketches and mockups to be evaluated via methods such as paper prototyping and wire framing).
Experimental Evaluations	The evaluation of new hard-coded interface and fully-functional system features in order to assess the features' impact on learning, motivation, and other outcomes of interest via laboratory or school-based experiments. Not all redesign projects pass through this phase, depending on the nature of the research questions and solutions.
Feedback and Implementation	The deployment of the educational technology in authentic learning settings with real stakes—typically, this means schools and classrooms in which students are trying to learn, teachers are trying to teach, and success is important.

In addition, the framework addresses the transitional relationships between phases to promote productive design and efficacious implementation in schools. The ultimate aim is to ensure that feedback collected from educational contexts is routed into a cycle of design and implementation in an attempt to improve the efficacy of the system.

Figure 2. The Design Implementation Framework

Defining and Evaluating the Problem

The initial stage entails identifying one or more central research questions or problems related to educational technology. These questions and needs can emerge from the developers' instructional or theoretical goals (e.g., a hypothesis that prompts students to self-explain will improve comprehension). Alternatively, problems may be revealed through end user feedback and implementation. Regardless of the source, researchers must carefully outline the scope and background of the problem. Necessarily, researchers must review the extant literature to situate the problem (or question) within the body of published research.

As a concrete example, consider the work done with W-Pal's teacher interface, described in the previous section. After discovering problems with assignment and progress information in the college classroom implementation and previous high school implementations, the authors set out to define the research questions to motivate the teacher interface redesign. After a review of previous implementation work and focus group data, the researchers settled on two main questions to frame the ideation phase: What decisions do teachers make in the classroom with student data? How can the design of W-Pal support those decisions?

Ideation

Once the problem is conceptually defined and explored via prior research, the developers can brainstorm a variety of plans for implementation or further investigation. This stage is naturally a creative process that can take many forms, producing incomplete and flawed ideas, and solutions that vary in specificity (Kudrowitz & Wallace, 2013; Paulus & Yang, 2000). Ideally, this stage is also collaborative—ideas should be contributed by multiple team members and perhaps participating end users. In addition, this stage can and should involve constructive critique and negotiation to identify potential flaws or opportunities. Importantly, by carefully defining the problem space in the first stage, idea generation activities are more likely to result in workable solutions and avoid missteps from the outset. Common problems such as laboriously recreating a known solution ("reinventing the wheel") or ineffective solutions ("red herrings") can be eliminated before consuming too much time.

Returning to the authors' W-Pal example, in weekly meetings, a team of eight researchers discussed solutions and a broader plan of execution to tackle the redesign of problem areas in the W-Pal teacher interface. To explore the research questions laid out above, the research team synthesized feedback from teacher focus group sessions and previous implementations. At the end of this process, the team found that teachers wanted skill-based information about writing to inform lesson planning and student grouping. Additionally, the researchers found that teachers wanted the ability to extract student writing and progress in a report to facilitate communication with parents and students. After meeting together to develop a procedural list of actionable items and priorities, the team decided to focus on developing assignment creation and student progress.

As the list of possible solutions is debated and narrowed, a clear choice may emerge that optimizes time, resources, and goal constraints. At this point, developers can proceed to design and testing stages. However, if multiple solutions seem equally viable, this presents an excellent opportunity for design research and experiments to contrast the alternatives before anything is implemented with the "live" system.

Design and User Experience

Plans resulting from the ideation stage will likely require the redesign of existing system features and/or the creation of new features. Rather than immediately reprogramming the "live" system back-end, interfaces, or other features, usability and user experience research methods can test and refine the designs. Developers create sketches and mockups to be evaluated via methods such as paper prototyping (Albert & Tullis, 2013) and wire framing (Roth, Hart, Mead & Quinn, 2016). A paper prototype is a sketch of a computer interface (on paper) with which users can simulate intended interactions, and wire frames are a digital platform for rapid design of semi-functional webpages. Both methods allow researchers to rapidly test designs without having to hard code the new features.

Design elements that are confusing, hard to locate or navigate, or even visually unappealing can be detected, rapidly edited, and then retested. These methods require few participants because the goal is not to evaluate efficacy or generalize to large populations—if even a handful of users find the design unusable, it is worth addressing those problems. When making such determinations, researchers can consult a variety of metrics such as the time to complete assigned tasks, error rates, and user utterances (e.g., complaints) (Albert & Tullis, 2013; Madan, & Dubey, 2012). Rapid and iterative cycles of such testing can be conducted until no more obvious problems remain.

To build out designs for the W-Pal assignment creation and progress pages, the research team created mockups using basic photo editing software. Wherever possible, the authors tried to build on elements of their reading ITS, iSTART (Snow, Jacovina, Jackson & McNamara, 2016), to avoid redeveloping features that had already been designed and coded in previous systems. For instance, the mockup of the assignment creation page used a calendar-based interface and drag and drop functionality that has recently been built into iSTART. To prepare for usability testing, mockups have recently been integrated into a wireframe, with clickable hotspots linking the different pages and feature mockups. In the near future, researchers plan to conduct usability studies using this wireframe. These studies will involve users engaging in tasks assessing initial impressions of the mockups as well as ask them to complete tasks, such as finding the game performance information for a particular student.

Experimental Evaluations

The "final" design, iteratively tested and refined, can then be evaluated via laboratory or school-based experiments. At this point, the new interface design is hard-coded and built into a fully functional system in order to assess the features impact on learning, motivation, and other outcomes of interest. However, not all redesign projects pass through this phase, depending on the nature of the research questions and solutions. For instance, it would be impossible to assess the effects of the W-Pal teacher interface redesign on student learning in the laboratory setting. Thus, the next step for that project will be to implement the system in schools and assess the value of the redesign through teacher interviews, surveys, and potentially in-class observations.

For projects that necessitate experimental evaluation, ideally the new design leads to significantly improved performance, improved usability, and positive user perceptions and attitudes with no negative "side effects." However, null results can also be telling. One of the challenges of educational technology development is that new features can be costly in terms of time and money, with more complex or nuanced designs incurring greater costs. Null results from experiments can reveal design directions that are unnecessary or low-value to pursue, ultimately resulting in savings down the line. For example, in a study of partial redundancy in multimedia presentations, researchers found that differences in the amount of text and narration overlap (ranging from 10% to 50% overlap) simply didn't matter (Roscoe, Jacovina, Harry, Russell, & McNamara, 2015). Thus, the degree of partial redundancy is not a concern for educational technology developers, as long as they do not violate the overarching redundancy principle (see Mayer & Johnson, 2008). Nonetheless, if results suggest a clear and beneficial course of action, the new features can be confidently incorporated within the actual system. Negative consequences or inconclusive results, however, necessitate a return to prior design stages.

Implementation and Feedback

Implementation refers to the deployment of the educational technology in authentic learning settings with real world stakes. Typically, this means schools and classrooms in which students are trying to learn, teachers are trying to teach, and success is important. It is worth noting that "success" must be defined within the local context. In some cases, demonstrable knowledge and skill growth is the goal; in other cases, a rewarding and fun experience is the goal. Similarly, after arriving at this shared definition of "efficacy," the team and stakeholders must also decide how it will be assessed. Assessments may include knowledge tests, classroom observations, teacher interviews, and surveys embedded in the technology. Although researchers may have specific hypotheses that entail certain kinds of measures, the assessment goals of collaborating partners should also be taken into account. Data on usability and user experience should be included along with other outcomes.

After design and usability testing for the W-Pal teacher interface, the authors plan on piloting the new features with teachers in classrooms. To continue to assess usability and efficacy of the assignment and progress features, they will conduct beginning and end of year teacher interviews, focusing on perceptions and classroom usage of the newly developed features. Mid-year surveys containing usability metrics and open-ended impression questions may also be used, in order to capture teacher experiences as their use of W-Pal develops.

Assessment data can be used not only to measure success, but also to reveal further design or implementation concerns. These issues may be minor (e.g., making an interface button more visible) or major (e.g., realizing that students ignored a critical feature), but each issue found and fixed makes the software incrementally more effective. However, when major problems, needs, or requests are encountered, the cycle might need to start over. After the initial design and development of a system, subsequent implementation research and data are the most likely sources for revealing critical design challenges.

SUMMARY

The five phases outlined by the DIF suggest a process of improvement in the design and development of a system such as W-Pal. The five phases included in the DIF—defining and evaluating the problem, ideation, design and user experience, experimental evaluations, and feedback and implementation—may be a helpful reference to researchers in the fields of educational technology, usability, and user experience. Ultimately, the authors aim to promote productive work environments and efficacious implementation in schools, with the underlying objective of utilizing user feedback to improve the efficacy of the system.

CONCLUSION

User-centered design methodologies that engage teacher participation at every stage of ITS development, design, and implementation will result in better systems. In this chapter, the authors articulated three broad principles that can and should guide such work, including participatory design, iteration, and usability considerations. Within this context, the critical role of teachers is also specifically emphasized. Teacher characteristics and barriers contribute to how and whether they integrate educational technologies within their instruction. To exemplify these principles, work carried out with W-Pal, a tutoring system for writing, was highlighted. Whenever researchers have sought out and incorporated student and teacher input, subsequent versions of the system were improved.

It is likely that researchers working on other systems may have similar anecdotal and experimental findings to share and the authors encourage more teams to publish such work. As a means of spurring such research and dissemination, the Design Implementation Framework (DIF) has been articulated. The DIF is, like an educational technology, a work in progress. The overarching intention is for DIF to serve as a heuristic for considering how design, testing, and implementation of ITSs intersect and coalesce.

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REFERENCES

Abras, C., Maloney-Krichmar, D. & Preece, J. (2004). User-centered design. In W. Bainbridge (Ed.), *Berkshire encyclopedia of human-computer interaction* (1st ed.). Berkshire Publishing Group.

Albert, W., & Tullis, T. (2013). *Measuring the user experience: Collecting, analyzing, and presenting usability metrics* (2nd ed.). Waltham, MA: Morgan Kaufmann.

Allen, L. K., Crossley, S. A., Snow, E. L., & McNamara, D. S. (2014). L2 writing practice: Game enjoyment as a key to engagement. *Language Learning & Technology*, *18*(2), 124-150.

Allen, L. K., Jacovina, M. E., Dascalu, M., Roscoe, R. D., Kent, K. M., Likens, A. D., & McNamara, D. S. (2016). {ENTER}ing the time series {SPACE}: Uncovering the writing process through keystroke analysis. In T. Barnes, M. Chi, & M. Feng (Eds.), *Proceedings of the 9th International Conference on Educational Data Mining, Raleigh, NC (EDM 2016)*, (pp.22-29). Raleigh, NC: International Educational Data Mining Society.

Anderson, J. R., Boyle, C. F., & Reiser, B. J. (1985). Intelligent tutoring systems. *Science (Washington)*, *228*, 456-462.

Annetta, L. A., Frazier, W. M., Folta, E., Holmes, S., Lamb, R., & Cheng, M. T. (2013). Science teacher efficacy and extrinsic factors toward professional development using video games in a design-based research model: The next generation of STEM learning. *Journal of Science Education and Technology*, *22*(1), 47-61.

Banathy, B. H. (1987). Instructional systems design. In R. Gagne (Ed.), *Instructional technology: Foundations* (pp. 85-112). Hillsdale, NJ: Lawrence Erlbaum Associates.

Becker, H. J. (1994). How exemplary computer-using teachers differ from other teachers: Implications for realizing the potential of computers in schools. *Journal of Research on Computing in Education*, *26*(3), 291-321.

Burns, H., Luckhardt, C. A., Parlett, J. W., & Redfield, C. L. (Eds.). (2014). *Intelligent tutoring systems: Evolutions in design*. Hove, England: Psychology Press.

Brandt, E. (2006). Designing exploratory design games: A framework for participation in Participatory Design? In G. Jacucci & F. Kensing (Eds.), *Proceedings of the Ninth Conference on Participatory Design: Expanding boundaries in design, 1,* (pp. 57-66). New York, NY: ACM.

Bravo, E. (1993). The hazards of leaving out the users. In D. Schuler & A. Namioka (Eds.), *Participatory design: Principles and practices* (pp. 3-11). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Brhel, M., Meth, H., Maedche, A., & Werder, K. (2015). Exploring principles of user-centered agile software development: A literature review. *Information and Software Technology*, *61*, 163-181.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences*, *2*(22), 141-178.

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

Chughtai, R., Zhang, S. & Craig, S. D. (2015). Usability evaluation of intelligent tutoring system: ITS from a usability perspective. Proceedings of the Human Factors & Ergonomics Society Annual Meeting (pp. 367-371). Los Angeles: SAGE.

Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology, 96,* (pp. 15-22). Springer Berlin Heidelberg.

Dai, J., Raine, R. B., Roscoe, R., Cai, Z., & McNamara, D. S. (2010). The Writing-Pal tutoring system: Development and design. *Journal of Engineering and Computer Innovations*, *2*(1), 1-11.

Danbjorg, D., Clemensen, J., & Rothmann, M. (2016). Participatory design methods in telemedicine. *International Journal of Integrated Care*, *16*(5)*: S11.*

Darling-Hammond, L., Barron, B., Pearson, P .D., Schoenfeld, A. H., Stage, E. K., Zimmerman, T. D., Cervetti, G. N. & Tilson, J. L. (2015). *Powerful learning: What we know about teaching for understanding*. San Francisco, CA: Jossey-Bass.

Dede, C., Nelson, B., Ketelhut, D. J., Clarke, J., & Bowman, C. (2004). Design-based research strategies for studying situated learning in a multi-user virtual environment. In Y. Kafai, W. Sandoval, & N. Enyedy (Eds.), *Proceedings of the 6th International Conference on Learning Sciences* (pp. 158-165). International Society of the Learning Sciences.

D'Mello, S. K. & Graesser, A. C. (2015). Feeling, thinking, and computing with affect-aware learning technologies. In R. A. Calvo, S. K. D'Mello, J. Gratch, & A. Kappas (Eds.), *Handbook of affective computing* (pp. 419-434). New York, NY: Oxford University Press.

Endsley, M. R. & Jones, D.G. (2011). *Designing for situation awareness: An approach to user-centered design* (2nd Ed.). Boca Raton, FL: CRC press.

Ertmer, P. A. (1999). Addressing first-and second-order barriers to change: Strategies for technology integration. *Educational Technology Research and Development*, *47*(4), 47-61.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education, 59*(2), 423-435.

Fishman, B. J., Penuel, W. R., Allen, A. R., Cheng, B. H., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *National Society for the Study of Education*, *112*(2), 136-156.

Fox, D., Sillito, J., & Maurer, F. (2008). Agile methods and user-centered design: How these two methodologies are being successfully integrated in industry. In *AGILE 2008 Conference* (pp. 63-72). Institute of Electrical and Electronics Engineers Press.

Gagne, R. M. (Ed.). (1987). *Instructional technology: Foundations*. New York, NY: Routledge.

Gibbons, A. S., Boling, E., & Smith, K. M. (2014). Instructional design models. In J. M. Spector, M. D. Merrill, J. Elen & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (pp. 607-615). New York: NY: Springer.

Goos, M. (2014). Researcher–teacher relationships and models for teaching development in mathematics education. *ZDM Mathematics Education*, *46*(2), 189-200.

Graesser, A. C., Li, H., & Forsyth, C. (2014). Learning by communicating in natural language with conversational agents. *Current Directions in Psychological Science*, *23*(5), 374-380.

Greenbaum, J. (1993). A design of one's own: towards participatory design in the United States. In D. Schuler & A. Namioka (Eds.), *Participatory design: Principles and practices* (pp. 27-37). HIllsdale, NJ: Lawrence Erlbaum Associates.

Hadley, M., & Sheingold, K. (1993). Commonalities and distinctive patterns in teachers' integration of computers. *American Journal of Education*, *101*(3), 261-315.

Heffernan, N. T., & Heffernan, C. L. (2014). The ASSISTments ecosystem: Building a platform that brings scientists and teachers together for minimally invasive research on human learning and teaching. *International Journal of Artificial Intelligence in Education*, *24*(4), 470-497.

Hermans, R., Tondeur, J., van Braak, J., & Valcke, M. (2008). The impact of primary school teachers' educational beliefs on the classroom use of computers. *Computers & Education*, *51*(4), 1499-1509.

Hervey, L. [Lisa Hervey]. (2013, January 28). TPACK Game. [Video File]. Retrieved from https://www.youtube.com/watch?v=7z3aP_Chj6c.

Holden, H., & Rada, R. (2011). Understanding the influence of perceived usability and technology self-efficacy on teachers' technology acceptance. *Journal of Research on Technology in Education*, *43*(4), 343-367.

Houseal, A. K., Abd-El-Khalick, F. and Destefano, L. (2014), Impact of a student–teacher–scientist partnership on students' and teachers' content knowledge, attitudes toward science, and pedagogical practices. *Journal of Research in Science Teaching*, *51*, 84–115.

Inan, F. A., & Lowther, D. L. (2010). Factors affecting technology integration in K-12 classrooms: A path model. Educational Technology Research and Development, *58*(2), 137-154.

Johnson, A. M., Jacovina, M. E., Jackson, G. T., Tighe, E. L., & McNamara, D. S. (2016). Lost in Springdale: An interactive narrative for adult literacy learners. In A. Micarellli, J. Stamper & K. Panourgia (Eds.), *Intelligent tutoring systems: 13th International Conference, ITS 2016, Zagreb, Croatia, June 7-10, 2016* (pp. 476-479). Springer.

Johnson, R., Severance, S., Leary, H., & Miller, S. (2014). Mathematical tasks as boundary objects in design-based implementation research. In J. L. Polman, E. A. Kyza, D. K. O'Neill, I. Tabak, W. R. Penuel, A. S. Jurow, K. O'Connor, T. Lee & L. D'Amico (Eds.), *Learning and becoming in practice: The International Conference of the Learning Sciences (ICLS) 2014*, (pp. 1127-1131), *2*. Boulder, CO: International Society of the Learning Sciences.

Kensing, F., & Blomberg, J. (1998). Participatory design: Issues and concerns. *Computer Supported Cooperative Work (CSCW)*, *7*(3), 167-185.

Ketelhut, D. J., Clarke, J., & Nelson, B. C. (2010). The development of River City, a multi-user virtual environment-based scientific inquiry curriculum: historical and design evolutions. In M. J. Jacobson & P. Reimann (Eds.), *Designs for learning environments of the future: International perspectives from the learning sciences* (pp. 89-110). Springer US.

Khaled, R., & Vasalou, A. (2014). Bridging serious games and participatory design. *International Journal of Child-Computer Interaction*, *2*(2), 93-100.

Kim, C., Kim, M. K., Lee, C., Spector, J. M., & DeMeester, K. (2013). Teacher beliefs and technology integration. *Teaching and Teacher Education*, *29*, 76-85.

Kim, L., McNamara, Danielle S., McCarthy, Philip, Dempsey, Kyle, Jackson, G. Tanner, Brandon, Russell, & Carney, Diana. (2012). Complications in user-centered design methodology: Overcoming social pressures in focus groups. Paper presented at *SIGDOC Symposium on Usability, Information Design, and Information Interaction to Communicate Complex Information*, Greenville, NC.

Kim, Y., & Baylor, A. L. (2016). Research-based design of pedagogical agent roles: A review, progress, and recommendations. *International Journal of Artificial Intelligence in Education*, *26*(1), 160-169.

Koehler, M. J., & Mishra, P. (2005). What happens when teachers design educational technology? The development of technological pedagogical content knowledge. *Journal of Educational Computing Research*, *32*(2), 131-152.

Könings, K. D., Seidel, T., Jeroen, J., & van Merriënboer, G. (2014). Participatory design of learning environments: Integrating perspectives of students, teachers, and designers. *Instructional Science*, *42*(1), 1-9.

Kudrowitz, B. M., & Wallace, D. (2013). Assessing the quality of ideas from prolific, early-stage product ideation. *Journal of Engineering Design*, *24*(2), 120-139.

Lebow, D. (1993). Constructivist values for instructional systems design: Five principles toward a new mindset. *Educational Technology Research and Development*, *41*(3), 4-16.

Lin, H. C. K., Chen, N. S., Sun, R. T. & Tsai, I. H. (2014). Usability of affective interfaces for a digital arts tutoring system. *Behaviour & Information Technology, 33*(2), 105-116.

Lin, H. C. K., Wu, C. H. & Hsueh, Y. P. (2014). The influence of using affective tutoring system in accounting remedial instruction on learning performance and usability. *Computers in Human Behavior*, *41*, 514–522.

Lowdermilk, T. (2013). *User-centered design: A developer's guide to building user-friendly applications*. Sebastopol, CA: O'Reilly Media.

Ma, W., Adesope, O. O., Nesbit, J. C., & Liu, Q. (2014). Intelligent tutoring systems and learning outcomes: A meta-analysis. *Journal of Educational Psychology*, *106*(4), 901-918.

Madan, A., & Dubey, S. K. (2012). Usability evaluation methods: A literature review. *International Journal of Engineering Science and Technology*, *4*(2), 590-599.

Mayer, R. E., & Estrella, G. (2014). Benefits of emotional design in multimedia instruction. *Learning and Instruction*, *33*, 12-18.

Mayer, R. E., & Johnson, C. I. (2008). Revising the redundancy principle in multimedia learning. *Journal of Educational Psychology*, *100*(2), 380-386.

McNamara, D. S., Crossley, S. A., & Roscoe, R. (2013). Natural language processing in an intelligent writing strategy tutoring system. *Behavior Research Methods*, *45*(2), 499-515.

McNamara, D. S., Jacovina, M. E., & Allen, L. K. (2015). Higher order thinking in comprehension. In P. Afflerbach (Ed.), *Handbook of individual differences in reading: Text and context*, (pp. 164-176). Taylor & Francis, Routledge: NY.

McNamara, D. S., Raine, R., Roscoe, R., Crossley, S., Jackson, G.T., Dai, J., Cai, Z., Renner, A., Brandon, R., Weston, J., Dempsey, K., Carney, D., Sullivan, S., Kim, L., Rus, V., Floyd, R., McCarthy, P. M., & Graesser, A.C. (2012). The Writing-Pal: Natural language algorithms to support intelligent tutoring on writing strategies. In P. M. McCarthy & C. Boonthum-Denecke (Eds.), *Applied natural language processing and content analysis: Identification, investigation, and resolution* (pp. 298-311). Hershey, P.A.: IGI Global.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.

Molenda, M. (2003). In search of the elusive ADDIE model. *Performance improvement*, *42*(5), 34-37.

Muldner, K., Lam, R., & Chi, M. T. H. (2014). Comparing learning from observing and from human tutoring. *Journal of Educational Psychology, 106*(1), 69-85.

Muller, M. J. (2003). Participatory design: The third space in HCI. In A. Sears & J. A. Jacko (Eds.), *Human-computer interaction: Development process* (pp. 165-185). Boca Raton, FL: CRC Press.

Nielsen, J. (1993). *Usability engineering*. Cambridge, MA: Academic Press Professional.

Nielsen, J. (2001, November 11). *Beyond accessibility: Treating users with disabilities as people*. Retrieved from https://www.nngroup.com/articles/beyond-accessibility-treating-users-with-disabilities-as-people.

Nye, B. D., Graesser, A. C., & Hu, X. (2014). AutoTutor and family: A review of 17 years of natural language tutoring. *International Journal of Artificial Intelligence in Education*, *24*(4), 427-469.

Oh, E., & Reeves, T. C. (2010). The implications of the differences between design research and instructional systems design for educational technology researchers and practitioners. *Educational Media International*, *47*(4), 263-275.

Pane, J. F., Griffin, B. A., McCaffrey, D. F., & Karam, R. (2014). Effectiveness of cognitive tutor algebra I at scale. *Educational Evaluation and Policy Analysis, 36*(2), 127-144.

Paulus, P. B., & Yang, H. C. (2000). Idea generation in groups: A basis for creativity in organizations. *Organizational Behavior and Human Decision Processes*, *82*(1), 76-87.

Penuel, W. R., & DeBarger, A. H. (in press). A research-practice partnership to improve formative assessment in science. In A. J. Daly & K. S. Finnigan (Eds.), *Thinking systemically: Improving districts under pressure*. Washington, DC: AERA.

Polly, D., McGee, J. R., Wang, C., Lambert, R. G., Pugalee, D. K., & Johnson, S. (2013). The association between teachers' beliefs, enacted practices, and student learning in mathematics. *Mathematics Educator, 22*(2), 11-30.

Roth, R. E., Hart, D., Mead, R., & Quinn, C. (2016). Wireframing for interactive & web-based geographic visualization: Designing the NOAA Lake Level Viewer. *Cartography and Geographic Information Science*, *44*(4), 1-20.

Roscoe, R. D., Allen, L. K., Weston, J. L., Crossley, S. A., & McNamara, D. S. (2014). The Writing Pal intelligent tutoring system: Usability testing and development. *Computers and Composition*, *34*, 39-59.

Roscoe, R. D., Brandon, R. D., Snow, E. L., & McNamara, D. S. (2013). Game-based writing strategy practice with the Writing Pal. In K. E. Pytash & R. E. Ferdig (Eds.), *Exploring technology for writing and writing instruction* (pp. 1-20). Hershey, PA: IGI Global.

Roscoe, R. D., Jacovina, M. E., Harry, D., Russell, D. G., & McNamara, D. S. (2015). Partial verbal redundancy in multimedia presentations for writing strategy instruction. *Applied Cognitive Psychology*, *29*, 669–679.

Roscoe, R. D. & McNamara, D. S. (2013). Writing Pal: Feasibility of an intelligent writing strategy tutor in the high school classroom. *Journal of Educational Psychology*, *105*(4), 1010-1025.

Roscoe, R.D., Varner, L.K., Cai, Z., Weston, J.L., Crossley, S.A., & McNamara, D.S. (2011). Internal usability testing of automated essay feedback in an intelligent writing tutor. In R. C.

Murray & P. M. McCarthy (Eds.), *Proceedings of the 24th International Florida Artificial Intelligence Research Society (FLAIRS) Conference* (pp. 543-548). Menlo Park, CA: AAAI Press.

Roscoe, R. D., Wilson, J., Johnson, A. C., & Mayra, C. R. (2017). Presentation, expectations, and experience: Sources of student perceptions of automated writing evaluation. *Computers in Human Behavior*, *70*, 207-221.

Snow, E. L., Allen, L. K., Jacovina, M. E., & McNamara, D. S. (2015). Does agency matter?: Exploring the impact of controlled behaviors within a game-based environment. *Computers & Education*, *82*, 378-392.

Snow, E. L., Jacovina, M. E., Jackson, G. T., & McNamara, D. S. (2017). iSTART-2: A reading comprehension and strategy instruction tutor. In D.S. McNamara & S. A. Crossley (Eds.), *Adaptive educational technologies for literacy instruction* (pp.104-121). New York, NY: Routledge.

Steenbergen-Hu, S., & Cooper, H. (2013). A meta-analysis of the effectiveness of intelligent tutoring systems on K–12 students' mathematical learning. *Journal of Educational Psychology*, *105(*4), 970-987.

Sugar, W. (2002). Applying human-centered design to technology integration: Three alternative technology perspectives. *Journal of Computing in Teacher Education*, *19*(1), 12-17.

Sung, E., & Mayer, R. E. (2012). Affective impact of navigational and signaling aids to e-learning. *Computers in Human Behavior*, *28*, 473-483.

Nieveen, N., McKenney, S. & van den Akker, J. (2006). Education design research: The value of variety. In J. Van den Akker, K. Gravemeijer, S. McKenney, & N. Nieveen (Eds.), *Educational design research*. Abingdon, England: Routledge.

VanLehn, K. (2006). The behavior of tutoring systems. *International Journal of Artificial Intelligence in Education*, *16*(3), 227-265.

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist*, *46*(4), 197-221.

Wiske, M.S. (1998). What is Teaching for Understanding? In M.S. Wiske (Ed.) *Teaching for understanding: Linking research with practice* (pp 61-86). San Francisco, CA: Jossey-Bass.

KEY TERMS AND DEFINITIONS

Design-Based Implementation Research: An approach to research where researchers and practitioners are connected in systematic inquiry, iteration, and collaboration. Development teams are formed to explicitly represent multiple perspectives to define and achieve common goals, identify problems, and negotiate solutions. DBIR emphasizes participatory design that is grounded in and responsive to local circumstances.

Design-Implementation Framework: A framework that connects research, design, and implementation processes to promote productive design and efficacious implementation in schools. It consists of five phases: 1) defining and evaluating the problem, 2) ideation, 3) design and user experience, 4) experimental evaluation, and 5) feedback and implementation.

Instructional Systems Design: A process that defines the state and needs of the learner, determines goals of instruction, and creates a sustainable implementation. One prominent Instructional Systems Design model is ADDIE.

Intelligent Tutoring Systems: Computer programs that emulate expert human tutors by instructing students on a specific topic or skill, providing feedback on responses, and strategically facilitating student performance and understanding.

Participatory Design: A practice of active engagement of prospective and authentic end users in a dialog with designers during the development of a product.

Research Partnerships: A formal arrangement where school districts and a research group(s) decide to work together to investigate a research question. Upon completion of the study, the research group usually shares the findings with the school and research community, potentially contributing to both local and systematic improvements in practice.

Writing Pal: An intelligent tutoring system that teaches persuasive writing strategies and features game-based strategy and writing practice. The system gives students formative and summative feedback on their writing using natural language processing algorithms.