Design-Based Research and Technology-Enhanced Learning Environments

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During the past decade, design-based research has demonstrated its potential as a methodology suitable to both research and design of technology-enhanced learning environments (TELEs). In this paper, we define and identify characteristics of design-based research, describe the importance of design-based research for the development of TELEs, propose principles for implementing design-based research with TELEs, and discuss future challenges of using this methodology.

☐ During the past decade, literature on the design of technology-enhanced learning environments (TELEs) has flourished. Multiple TELE theoretical frameworks, especially those based on constructivist epistemology (Cognition and Technology Group at Vanderbilt [CTGV], 1992a, 1992b; Hannafin, Land, & Oliver, 1999; Savery & Duffy, 1996), have been proposed. TELEs are technology-based learning and instructional systems through which students acquire skills or knowledge, usually with the help of teachers or facilitators, learning support tools, and technological resources (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Land, 2000; Shapiro & Roskos, 1995). In recent years, with the rapid development of new technologies (e.g., computers, wide-area Internet, and PDAs), TELEs have generated considerable enthusiasm within the design community. However, as with previous teaching-learning innovations, design and research have evolved in a largely sequential manner, with little direct influence on practice. As a result, TELEs have not been widely used by either students or teachers (Cuban, 1986, 2001; Kent & McNergney, 1999).

The design-based research paradigm, one that advances design, research *and* practice concurrently, has demonstrated considerable potential. Advanced initially by Brown (1992) and Collins (1992) as *design experiments,* design-based research posits synergistic relationships among researching, designing, and engineering. Design experiments manifest both scientific and educational values through the active involvement of researchers in learning and teaching procedures and through "scientific processes of discovery, exploration, confirmation, and dissemination" (Kelly, 2003, p. 3). Design-based research challenges the assumption that research is contaminated by the external influence of the researcher (Barab & Kirshner, 2001). Instead, researchers manage research processes in collaboration with participants, design and implement *interventions* systematically to refine and improve initial designs, and ultimately seek to advance both pragmatic and theoretical aims affecting practice.

In many ways, design-based research is intrinsically linked to, and its development nourished by, multiple design and research methodologies. Researchers assume the functions of both designers and researchers, drawing on procedures and methods from both fields, in the form of a hybrid methodology. For example, design-based research requires significant literature review and theory generation, uses formative evaluation as a research method, and utilizes many data collection and analysis methods widely used in quantitative or qualitative research (Orrill, Hannafin, & Glazer, 2003; Reigeluth & Frick, 1999). In these regards, design-based research does not replace other methodologies, but rather provides an alternative approach that emphasizes direct, scalable, and concurrent improvements in research, theory, and practice.

In other ways, however, the convergence of design research, theory, and practice extends current methodologies. For example, participatory action research—a qualitative approach akin to design-based research—involves collaboration between researchers and participants, local practices that support systematic theorizing, and improvement in both theory and practice. However, local improvements in participatory action research typically derive from participants' own research that is *facilitated* by researchers rather than interventions designed and progressively refined jointly with researchers (see Kemmis & McTaggart, 2000; Patton, 2002; Stringer, 1999). Likewise, intervention design—sometimes equated with formative evaluation—is often undertaken to generate evidence used to guide possible revisions in an ongoing design (Reeves & Hedberg, 2003). Design-based research is both based on, and conducted in order to generate, theory; the simultaneous pursuit of theoretical goals differentiates design-based research from formative evaluation (Barab & Squire, 2004).

In TELE practice, design-based research methods have been utilized widely, including technology-supported inquiry learning (TSIL; Edelson, Gordin & Pea, 1999), Web-based inquiry science environment (WISE) and its forerunner knowledge integration environment (KIE; Bell & Linn, 2000; Linn, Clark, & Slotta, 2003; Linn, Davis, & Bell, 2004), the Jasper Woodbury Series (CTGV, 1992a, 1992b, 1997), biology guided inquiry learning environment (BGuILE; Reiser et al., 2001; Sandoval & Reiser, 1998, 2004), and computer-supported intentional learning environments (CSILE; Hewitt & Scardamalia, 1998; Scardamalia & Bereiter, 1994). The purposes of this paper are to define and identify characteristics of design-based research, describe its importance for the development of TELEs, propose principles for implementing design-based research in TELEs, and identify future prospects for design-based research in TELE and instructional design.

AN INTRODUCTION TO DESIGN-BASED RESEARCH

We use the term *design-based research* (Design-Based Research Collective [DBRC], 2003) to encompass a paradigm described using different terms in the literature, including design experiments (Brown, 1992; Collins, 1992), design research (Cobb, 2001; Collins, Joseph, & Bielaczyc, 2004; Edelson, 2002), development research (van den Akker, 1999), developmental research (Richey, Klein, & Nelson, 2003; Richey & Nelson, 1996), and formative research (Reigeluth & Frick, 1999; Walker, 1992). As summarized in Table 1, each has a slightly different focus, but the underlying goals and approaches are similar.

To underscore both the similarities among and distinctions between design-based research and related methods, we define *design-based research* as a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world set-

Table 1 ☐ Design-based research variants and methods.

Variant & Referance	*Method*
Design-based research (Design-Based Research Collective, 2003)	• Often conducted within a single setting over a long time. • Iterative cycles of design, enactment, analysis, and redesign. • Contextually dependent interventions. • Document and connect outcomes with development process and the authentic setting. • Collaboration between practitioners and researchers. • Lead to the development of knowledge that can be used in practice and can inform practitioners and other designers.
Design experiments (Collins, 1992, 1999)	• Comparison of multiple innovations. • Characterizing the messy situation. • Multiple expertise in design. • Social interaction during design. • Flexible design revision and objective evaluation. • Developing a profile as findings.
Design research (Edelson, 2002)	• Designs both directly propel the development of practice and improve researchers' understanding. • Four characteristics: research driven, systematic documentation, formative evaluation, generalization. • Design generates three types of theories: domain theories, design frameworks, design methodologies; these theories go beyond the specific design context.
Development research (van den Akker, 1999)	• Begin with literature review, expert consultation, analysis of examples, and case studies of current practice. • Interaction and collaboration with research participants to approximate interventions. • Systematic documentation, analysis, and reflection on research process and outcomes. • Using multiple research methods; formative evaluation as the key activity. • Empirical testing of interventions. • Principles as generated knowledge in the format of heuristic statements.
Developmental research (Richey, Klein, & Nelson, 2003)	• *Type 1* (emphasizing specific product or program) and *Type 2* (focusing on the research process). • Begin with defining research problem and reviewing related literature. • Different participating populations in Type 1 and Type 2 developmental research during different phases. • Various forms of data collection depending on the research focus. • Employ multiple research methods, such as evaluation, field observation, document analysis, in-depth interview, expert review, case study, survey etc. • Data analysis and synthesis include descriptive data representations, quantitative and qualitative data analyses. • Reports of developmental research are long and can be published in various types of sources; websites are useful to report massive data sets.
Formative research (Reigeluth & Frick, 1999)	• Drawn from case-study research and formative evaluation. • Used to improve instructional systems and to develop and test design theory in education. • Preferability (i.e., effectiveness, efficiency, and appeal) over validity. • Two types: (a) designed case studies and (b) naturalistic case studies.

tings, and leading to contextually-sensitive design principles and theories. The five basic characteristics: (a) pragmatic; (b) grounded; (c) interactive, iterative, and flexible; (d) integrative; and (e) contextual, are summarized in Table 2 and illustrated in the following sections, and represent a synthesis of related approaches shown in Table 1. As noted previously, many characteristics are not unique to design-based research, but rather the nature of their use varies and the approaches are often extended in design-based research.

Table 2 ☐ Characteristics of design-based research.

Characteristics	*Explanations*
Pragmatic	• Design-based research refines both theory and practice. • The value of theory is appraised by the extent to which principles inform and improve practice.
Grounded	• Design is theory-driven and grounded in relevant research, theory and practice. • Design is conducted in real-world settings and the design process is embedded in, and studied through, design-based research.
Interactive, iterative, and flexible	• Designers are involved in the design processes and work together with participants. • Processes are iterative cycle of analysis, design, implementation, and redesign. • Initial plan is usually insufficiently detailed so that designers can make deliberate changes when necessary.
Integrative	• Mixed research methods are used to maximize the credibility of ongoing research. • Methods vary during different phases as new needs and issues emerge and the focus of the research evolves. • Rigor is purposefully maintained and discipline applied appropriate to the development phase.
Contextual	• The research process, research findings, and changes from the initial plan are documented. • Research results are connected with the design process and the setting. • The content and depth of generated design principles varies. • Guidance for applying generated principles is needed.

Pragmatic

Researchers address practical issues to promote fundamental understanding about design, learning, and teaching (Orrill et al., 2003). The Jasper Series (CTGV, 1997), for example, was developed and improved through its applications, progressively refining the theory of anchored instruction that has widely informed TELE design and practices. Similarly, the fostering communities of learners (FCL) project (Brown & Campione, 1996), conducted in inner-city elementary schools for more than a decade, typifies this synergy as researchers collaborate with teachers and students. Following iterative design, development, and implementation, learning principles useful for both *conceptual understanding* and *practical dissemination* are generated, based on the research procedures and settings.

From a design-based research perspective, theory development is inextricably linked to practice (Brown & Campione, 1996); research should refine both theory and practice (Collins et al., 2004) as well as provide new possibilities. Ultimately, the value of theory is appraised by the extent to which principles and concepts of the theory inform and improve practice (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; DBRC, 2003; Greeno, Collins, & Resnick, 1996). In addition to asking *whether* a theory works, researchers further question *how well* the theory works; that is, whether a given theory is better (i.e., more effective in achieving the design goals, cost efficient, and appealing to stakeholders) than known alternatives to attaining a desired outcome, and how research might refine the theory (Reigeluth & Frick, 1999). The pragmatic goal of design-based research is continually reified through disciplined application of its methodologies and research processes.

Grounded

Before conducting design-based research, researchers select a theory about learning and instruction. They examine literature and available design cases, and identify gaps to ensure the value of the research (Edelson, 2002) and to identify existing problems or issues (e.g., specific student learning abilities; Cobb et al., 2003). In subsequent efforts, they seek to revise and refine that theory—an "anchor" that determines which interventions should (or should not) be introduced and which should be eliminated. BGuILE (Reiser et al., 2001), for instance, is derived from an analysis of literature related to scientific inquiry. This analysis led to its two major theoretical goals—(a) observational investigations and (b) theory articulation—which are supported by all design efforts, ranging from determining the characteristics of inquiry products, through selecting investigation strategies, to designing tools and artifacts (Reiser et al.). The theory-driven nature of design-based research is important in that its approaches are considered more a research paradigm than an evaluation method. Without underlying theory support for both the framework and design procedures employed, results often fail to inform theory development for design innovation in education (Collins, 1992). Thus, the methods need to be grounded in relevant research, theory, and practice to develop future innovations and designs.

Design-based research is also grounded in real-world contexts where participants interact socially with one another, and within design settings rather than in laboratory settings isolated from everyday practice (Brown & Campione, 1996; Collins, 1999). Thus, design-based researchers address simultaneously the multitude of variables evident in real-world settings (Collins, 1992, 1999). Researchers observe different aspects of the design using both quantitative and qualitative methods, address associated problems and needs, and document why and how adjustments are made (Collins et al., 2004). Furthermore, by embedding research within practical activities, the design processes themselves are studied. The resulting principles are perceived as having greater external validity than those developed in laboratory settings (Greeno et al., 1996) and as better informing long-term and systemic issues in education (Bell, Hoadley, & Linn, 2004). Thus, the design process is embedded in, and studied through, design-based research.

Interactive, Iterative, and Flexible

Design-based research stresses collaboration among participants and researchers throughout the processes (Cobb et al., 2003). Because of dynamic and complex relationships between theory and practice, direct theory application without practitioner interaction is often not feasible; thus, researchers and practitioners work together to identify approaches and develop principles to address these problems (Schwartz, Lin, Brophy, & Bransford, 1999; van den Akker, 1999). Although distinctions among designers, researchers, and participants are blurred in design-based research processes (Bannan-Ritland, 2003), researchers manage the design process, cultivate the relationship with practitioners, and most importantly, develop their understanding of the research context (Cobb et al., 2003). In WISE, Linn et al. (2003) provided an initial flexible framework that incorporated both general technology features and instructional resources, and teaching-learning strategies. However, many features ultimately emerged from or were adapted based on input from participants. Project partner-participants (i.e. design teams, including classroom teachers, pedagogy researchers, curriculum designers, technologists, and discipline experts) developed, tested, and refined their individual inquiry projects based on the framework, helping to refine WISE content, user interface, and affordances. Hence, design researchers seek to shape the local learning environment by applying their expertise to improve educational practice (Barab & Kirshner, 2001; van den Akker, 1999); likewise, research and theory evolve in concert with advances in practice, ensuring that complementary expertise and different perspectives contribute to the design (DBRC, 2003). With the involvement of both researchers and participants, emerging local issues can also be addressed in an efficient and timely manner. Consequently, the design may be better optimized given the constraints of the local setting and addressing participant concerns.

Design-based research is also characterized by an iterative cycle of design, enactment or implementation, analysis, and redesign (DBRC, 2003). Outcomes from previously conducted designs provide explanatory frameworks "that specif[y] expectations that become the focus of investigation during the next cycle of inquiry" (Cobb et al., 2003, p.10). For example, research conducted prior to the emergence of the Jasper Series revealed inert-knowledge problems (i.e., knowledge recallable but not applied to solving problems). To address this problem, CTGV researchers initiated and subsequently focused their research on anchored instruction through which instruction was situated in meaningful, problem-rich learning environments (CTGV, 1992a, 1997).

Design-based research processes are also flexible, as collaborators seek to improve an initial design plan through implementation. Schwartz et al. (1999) suggested that designs should be flexibly adaptive but "consistent with important principles of learning" (p. 189). During implementation, a theory emerges based on the accumulated data collected during successive iterations as well as the implementation experiences of the designers (Edelson, 2002). The theoretical framework upon which the design is based may be extended and developed; in some cases, a new framework may emerge. Initial design plans may be insufficiently detailed to account for emerging patterns, so changes are anticipated and implemented when necessary (Cobb et al., 2003; Collins, 1999; Edelson, 2002).

In addition to improving the ongoing design, researchers also consider the influence of en route changes on the integrity of the design. During FCL development, Brown and Campione (1996) found that adaptive reciprocal teaching (RT) reading strategies were less useful than research seminar (RS) for older students. However, the researchers chose not to simply replace RT with RS for older students because the RT functions were also linked to other key activities in the project (e.g., information sharing, student writing or publishing). In other words, "any changes to one aspect of the design" need to be compatible "with other aspects of the design" (Collins et al., 2004, p. 19). Thus, researchers need to balance their roles as designer and researcher to ensure that practical constraints are considered, alternative perspectives are provided, and discipline in the inquiry is ensured (van den Akker, 1999).

Integrative

Design-based research draws from a variety of widely used approaches, such as survey, expert review, evaluation, case study, interview, inquiry methods, and comparative analysis (see, e.g., McCandliss, Kalchman, & Bryant, 2003; Richey et al., 2003). By using a combination of methods, data from multiple sources increase the objectivity, validity, and applicability of the ongoing research. Sandoval and Reiser (2004) conducted design-based research on Explanation-Constructor, a tool "designed to support students' construction and evaluation of explanations through their inquiry" (p. 348). In order to understand the role of their tool in students' epistemic practices, researchers videotaped groups of student activities and analyzed them using interaction analysis. Likewise, in order to "understand students' practices of explanation evaluation" (p. 363), researchers collected self-assessments and peer critiques from student activities and subsequently conducted documentation analyses.

Methods may also vary as new needs and issues emerge and the focus of the research evolves. Researchers may initially conduct observations to document changes in the classroom environment while using surveys or tests to collect data on student performance. During development, the emphasis on quality shifts from validity to practicality and effectiveness, and design researchers may employ expert appraisals, tryouts, microevaluations, or field tests (van den Akker, 1999) as warranted by the changing research focus. For example, during early stages of a TELE design, researchers may focus on the robustness of its theoretical anchors and the consistency between the planned interventions and the theoretical goals of the research. When developing and implementing the design, however, they may put more emphasis on the feasibility of the design in the classroom, and assess whether the theoretical goals can be achieved through the interventions. Rigor is purposefully maintained, ensuring adherence to discipline and scientific research standards and conventions (Shavelson, Phillips, Towne, & Feuer, 2003).

Retrospective analysis and formative evaluation are employed by some design researchers. Through retrospective analysis of collected data and design events, evidence-based claims and results are examined in concert with the underlying design theory; implicit design elements become explicit to further guide subsequent analysis and research activities (Battista & Clements, 2000; Cobb et al., 2003; Edelson, 2002). During diSessa and Cobb's (2004) design-based research on the teaching of physics, several issues emerged beyond the planned focus of their study. The researchers expected that students would neither intensively engage in designing graphs about motion nor continue to discuss possibilities for improving their graphs after class. Retrospective analysis on newly emerged issues enabled the researchers to identify a phenomenon known as *meta-representational competence*—students' prior knowledge that supported their abilities to create, critique, and adapt scientific representations. This competence was not initially anticipated from existing literature, but became the focus of their subsequent inquiry.

Formative evaluation typically focuses on the local design, exposes issues to be addressed through design research, and enables researchers to identify problems and gaps (Edelson, 2002; Reigeluth & Frick, 1999; van den Akker, 1999). In the Jasper project (CTGV 1997), for instance, formative evaluation revealed that the Jasper challenge series was especially effective when students have opportunities "to engage in problem-based curricula" (p. 108). Consequently, CTGV researchers recommended that "teachers provide students with multiple opportunities to "*I*dentify problems to be solved, *D*evelop plans, *A*ct on them, *R*eceive feedback and *R*evise as necessary" (p. 104).

Contextual

According to design-based research advocates (e.g., Brown & Campione, 1996; DBRC, 2003; van den Akker, 1999), research results need to be connected with both the design process through which results are generated and the setting where research is conducted. The findings generated from design-based research take many forms. They may be comparative profiles akin to a consumer report (Collins et al., 2004), principles in the form of heuristics, case studies, or longitudinal studies. The findings are more than prescribed activities to be followed by other designers; they transcend the immediate problem setting and context to guide designers in both evolving relevant theory and generating new findings. According to van den Akker (1999), the generalizability of findings increases when they are validated in "successful design of more interventions in more contexts" (p.9).

Two studies on CSILE underscore the importance of context. Consistent with literature indicating that student online discussion promotes equality. Scardamalia et al. (1992) and Hewitt (1996) found that students at different ability levels perform equally when using computers as their discourse medium. However, compared to face-to-face communications, students' online communication also results in less immediate feedback from others on their individual work. To address these issues in classroom practices, teachers encourage collaboration between students to review their peers' work during their CSILE sessions. These studies and implementations led CSILE researchers to identify a design principle—"support educationally effective peer interactions." This principle is "particularly effective in fostering educationally-beneficial distributed practices" (Hewitt & Scardamalia, 1998, p. 56) when used together with other related CSILE principles (e.g., integrating different forms of discourse, emphasizing the work of the community).

The research process, the research findings, and changes from the initial research plan haave been documented; warrants, claims, and guidance on the use of resulting principles have been provided (Shavelson et al., 2003). Thus, interested researchers or designers can trace the emergence of an innovation or combinations of innovations according to their interests, examining closely contextual factors or conditions that led to particular effects (Baumgartner & Bell, 2002). The content and depth of design principles vary. Principles may be generic and based on the findings of multiple research results, or, content specific to assist direct action (Bell et al., 2004). A series of design studies on the Computer as Learning Partner curriculum, focusing on science learning and instruction, generated four generic, but cornerstone, principles of the scaffolded knowledge framework: (a) making science accessible, (b) making thinking visible, (c) helping students learn from others, and (d) promoting autonomy and lifelong learning (Linn & Hsi, 2000). In contrast, Edelson et al.'s (1999) research on TSIL, featuring scientific visualization technologies in the geosciences, generated two content-specific principles: (a) "the design of investigation tools could . . . [address] the challenges of motivation, accessibility, and practical constraints"(p. 442); (b) "knowledge resources and record-keeping tools" (p. 444) are necessary process supports for inquiry-based learning. These principles were particularly helpful for the specific inquiry-based learning case under study, but may not apply across domains.

Given the assumption that comparable performance is most likely in similar settings, contextually relevant design principles and knowledge are important for design-based researchers. Because of the complex and dynamic nature of education, a myriad of context-specific and context-dependent variables influences any given innovation (Brown & Campione, 1996; Collins, 1999; van den Akker, 1999). As a result, the results from broadly contextualized research methods may prove too global and abstract to be useful in many settings (Baumgartner & Bell, 2002; Cobb, 2001; Cobb et al., 2003).

In contrast, the principles derived from typical design-based research are relevant to designs and development tasks where parallel contextual conditions exist (van den Akker, 1999). Brophy (1998) designed the Questioning Environment to Support Thinking (QUEST) project that "structures media resources to help students sustain their own inquiry during problem solving" (p. 6). QUEST employs a four-stage problem-solving model: (a) problem presentation, (b) information exploration, (c) discovery, and (d) reflection on solutions. QUEST's designers referenced anchored instruction research and theory (CTGV, 1997) extensively, providing relevant references on design and implementation of meaningful, problem-oriented activities to facilitate learning. More importantly, these principles are systematically aligned with the research context. They may prove ineffective when used alone but they can be modified, replaced, or adapted by others provided the system itself remains unaffected. Thus, researchers attempt to analyze the relationship between principles (e.g., the order of implementing them, the interdependencies between them) so that the design procedures they employ in the original setting will likely prove effective in new settings (Brown & Campione, 1996). Guidance for applying generated principles is needed to increase the adaptability, and ultimately the generalizability, of the research.

IMPORTANCE OF DESIGN-BASED RESEARCH FOR TELES

Design-based methodologies are especially important considering that TELEs have often been developed using incompatible or contradictory theoretical and epistemological foundations (Hannafin, Hannafin, Land, & Oliver, 1997). Consequently, gaps are evident between what a TELE is and how it should be used in theory compared with what it is and how it is used in practice. Alternative approaches are needed to align learning environments with their fundamental assumptions (Hannafin, et al., 1997; Jonassen & Rohrer-Murphy, 1999) and "encourage flexibility as well" (Schwartz et al., 1999, p. 189). Design-based research emphasizes closely linked strategies for developing and refining theories rather than testing intact theories using traditional methodologies (Edelson, 2002). Design-based research guides theory development, improves instructional design, extends the application of results, and identifies new design possibilities (Cobb et al., 2003; Edelson, 2002; Gustafson, 2002; Reigeluth & Frick, 1999). Design-based research can "help create and extend knowledge about developing, enacting, and sustaining innovative learning environments" (DBRC, 2003, p. 5).

Several aspects of design-based research are consistent with TELE design theories (e.g., iterative design process, collaboration with participants), which in turn are helpful to the development of design-based research methods. In the following sections, we highlight three implications of design-based research for TELEs:

(a) encouraging continuous synergy, (b) refining TELE theory, and (c) encouraging socially responsible and responsive inquiry and practice.

Encouraging Continuous Synergy

In traditional instructional design (ID) and instructional systems design (ISD) approaches, design and research are typically related, but separate, activities. Research is usually conducted after ID/ISD processes have been completed, to test the design's effectiveness rather than to address issues of educational practice (Cobb et al., 2003). The emergence of grounded design practice and design-based research addresses a core TELE problem: the lack of clearly defined and enacted theoretical frameworks applicable to practice. In ID/ISD practice, the need for an integral relationship between design and research is underscored in Hannafin et al.'s (1997) criteria for grounded design practice: (a) designs must be based on a defensible or widely acknowledged theoretical framework; (b) methods must be consistent with the outcomes of research conducted to test, validate, or extend the theories on which they are based; (c) designs are generalizable; and (d) designs and their frameworks are validated iteratively through successive implementation.

Design-based research posits synergy between practice and research in everyday settings. This synergy engenders simultaneous refinements of theory and practice as theory is generated and refined through its application; in effect, educational approaches and theory emerge reciprocally (Bell et al., 2004). Synergy helps to generate principles that inform the design itself as well as the thinking and actions of researchers, designers, and practitioners. Design-based research can extend and develop both grounded design practices generally and TELE design theories specifically.

Accordingly, TELE design and research activities can become more reciprocal: the design of learning environments and development of learning theories can be intertwined (DBRC, 2003). Strong theoretical anchors support design work, forming "the most immediate foundation for the discipline in which the original problem arose" (Winn, 1997, p. 38). Theories generated from designs are often supported by examining learning in naturalistic contexts and through developing innovations, technological tools, and theories (Barab & Squire, 2004). Inconsistencies between theory and practice can be revealed through "the practical process of applying a theory to construct a design" (Edelson, 2002, p. 118). The theories are of practical use to resolve problems and cannot be generated by "either isolated analysis or traditional empirical approaches" (Edelson, p.118).

Research supports design reciprocally in design-based research, providing frequent and often subtle refinement guided by detailed data (Cobb, 2001). Designs are evidence based, that is, they engender tangible changes in TELE practice, ranging from the impact to the ongoing design resulting from a specific innovation or a combination of innovations, to the influences of theories generated from other TELE research. TELE designers use evidence to refine the design, to address new or emerging issues, to support new theory or approaches to deepen understandings of TELE research and practice, and to guide further research and theory construction. Moreover, design-based research enables the creation and study of learning conditions that are presumed effective but are not well understood in practice, and the generation of findings often overlooked or obscured when focusing exclusively on the summative effects of an intervention (DBRC, 2003). In effect, design is embodied in research, and research is embodied in design.

The synergy between design and research is typified in Sandoval and Reiser's (2004) refinements of ExplanationConstructor. Initial classroom research provided detailed confirmatory evidence that their tool guided student inquiry as predicted from its conceptual framework, which focused on "the influence of epistemological commitments on strategies for pursuing inquiry" (p. 347). However, their data indicated that the tool was unsuccessful in supporting student ideas or interpreting the data they needed to explain. The tool was revised accordingly, enabling students to cite data directly in their explanations and incorporating a review feature to support assessment. Studies on the revised

ExplanationConstructor resulted in principles related to the design of tools for supporting students' scientific practice, and structuring explanations, and subsequent evaluation, as well as limitations in supporting scientific argumentation.

Refining TELE Theory

Richey et al. (2003) proposed two types of developmental research. Type 1 research is context specific; conclusions typically take the form of lessons learned from the development of a specific product and conditions that improve the effectiveness of that product. Type 2 research, in contrast, yields generalizable design procedures or principles. Likewise, Edelson (2002) identified three types of theories of potential relevance to TELE: (a) domain theories, (b) design frameworks, and (c) design methodologies. *Domain theories* are descriptive in nature and concern the nature of the problem or issue under study, such as the challenges and opportunities in a middle-school science course, and findings associated with students' using an online learning environment of scientific investigation. *Design frameworks* are systemic guidelines and generalized solutions to achieve an array of goals in a specific context, such as open-ended learning environments (Hannafin et al., 1999) and goal-based scenarios (Schank, Fano, Bell, & Jona, 1994). *Design methodologies* are generic procedures that guide the process, such as how to achieve a design goal and develop the needed expertise. Both design frameworks and design methodologies are prescriptive in nature.

In TELE designs, new ideas can emerge from decision-making processes in the form of context-based knowledge and meta-design knowledge. Both Type 1 and Type 2 research identified by Richey et al. (2003) are emphasized in design-based research. Context-based knowledge focuses on problems and issues specific to a given TELE design, including relevant domain theories and knowledge generated from Type 1 research. Meta-design knowledge emphasizes principles, procedures, and frameworks that provide more generally useful design guidance, including design frameworks, design procedures, and knowledge generated through Type 2 research. Context-based knowledge and meta-design knowledge are interwoven in design-based research iterative design, development, and implementation processes.

Both types of knowledge were generated during the development of the Jasper Series. Context-based knowledge resides in many domains, including curriculum design, instruction and assessment, formative assessment, and teacher learning and learning communities. Meta-design knowledge includes new design frameworks, such as anchored instruction, and the looking at technology in context framework (CTGV 1992a, 1992b, 1997). Likewise, Brophy (1998) compared problem-solving processes of students using the simulated QUEST environment or wet-lab equipments. The context-based knowledge that emerged focused on the effectiveness of treatments used in this study: "problem solving contexts encourage qualitative thinking" (p. 25), and instruction started with problems could result in more self-directed learning. The meta-design knowledge that emerged—establishing a learning context for student knowledge building—focused on clarifying the goals of, and evaluating success in, classroom technology integration.

With design-based TELE research, meta-design knowledge and context-based knowledge transcend specific designs for theory development purposes (Edelson, 2002). Meta-design knowledge becomes more credible and applicable because it is based on research results from not only the current design but from related studies as well. Additionally, both context-based knowledge and meta-design knowledge are fully specified. Multiple aspects of practice are reflected through iterative research and continuous refinement (Greeno et al., 1996; van den Akker, 1999). In complex designs, TELE designers can identify the relevance of context-based knowledge derived from other TELEs and reliably anticipate the effectiveness and efficiency of new tools, models, and principles (Richey et al., 2003). They can also avoid mistakes, assimilate valuable experiences from both results and processes of the designs, and decide whether to use or adapt proven approaches in their designs.

Encouraging Socially Responsible and Responsive Inquiry and Practice

According to Fullan (2001), educational researchers must strive harder to improve the circumstances of individuals, as well as policies and resources in both local and remote settings. During recent years, researchers have questioned why educational research has failed to influence practice, the trends and directions of research and development, and the strength of the link between research and practice (Berliner, 2002; Burkhardt & Schoenfeld, 2003). In Collins's (1992) criticism of traditional experimental studies, he concluded that only significant effects are typically tested in a single design; designs are too variable for any valid class conclusions to be drawn; and underlying theories are rarely provided to support the design. In addition, van den Akker (1999) criticized that complex and ambitious reform policies in educational practice are often ill specified; the effectiveness of proposed interventions is unknown, and the implementation process in various contexts is uncertain. Many researchers now seek pragmatic methodologies that invest more genuinely the practitioners who implement innovation in everyday settings, encouraging the refinement of goal-oriented theories that support practice (Peterson, 1998; Reigeluth, 1997; Robinson, 1998).

Design-based research has the potential to generate theories that both meet teachers' needs and support educational reforms (Reigeluth & Frick, 1999). For example, Fishman, Marx, Blumenfeld, and Krajcik (2004) described their research on integrating technology-enhanced, inquiry-based science curricula as part of the Detroit Public Schools educational reform initiative. They initially designed and implemented technology innovations with design-based research approaches, then attempted to expand the innovations to other settings in the city. During the process, they encountered unforeseen challenges to their implementation, identified teacher preparation and organizational gaps "between the capacity of the district and demands of the innovations" (p. 56), and proposed research to narrow the gaps. Moreover, *design* reflected teacher perspectives and helped teachers to better understand the implications of TELEs in student learning. Likewise, WISE teachers contributed to its inquiry focus using both their knowledge and awareness of their classroom contexts, while becoming increasingly skilled in guiding student inquiry processes (Linn et al., 2003). Improvements in both local and remote settings, with teachers' concerns addressed and their expertise utilized, may help to promote wider classroom application of TELEs.

PRINCIPLES OF DESIGN-BASED RESEARCH

As with all disciplined inquiry, design-based research implementations need to be both purposeful and systemic. In these regards, design-based research parallels instructional design in many ways. Traditional ID activities are applied to address local design needs and requirements—a goal shared by design-based research. To generate practical, credible, and contextual design theories, however, rigorous, disciplined, and iterative inquiry is needed. Design-based research extends the immediate local goal shared by traditional ID designers to generate pragmatic and generalizable design principles. Therefore, design activities and research activities usually cannot be conducted separately; systematic ID processes can be referred to design-based research procedures. As described in the following sections, we identify nine principles central to planning and implementing TELE design-based research.

Principle One: Support Design with Research from the Outset

Prior to proceeding, designers need to identify resources relevant to their project needs using available literature and design cases from multiple sources, such as journal publications, research reports, conference proceedings, and technical reports. In instances where topic- or issue-specific research cannot be identified, consider literature indirectly linked to the theoretical foundation of the design or extrapolate guidance from related research (Richey et al., 2003).

By analyzing available literature and the design setting critically, designers may also gain different insights as to underpinnings and focus. For example, after reviewing literature on inquiry-based science learning and related design cases, Edelson et al. (1999) initially identified the purpose of the TSIL research as "to understand the opportunities and obstacles presented by scientific visualization as technology to support inquiry-based learning" (p.392) and focused on technological issues. After analyzing the design setting, however, they identified the need to account for both technological and curricular strategies (e.g., students' management skills, motivation, background knowledge), ultimately developing visualization environments and curriculum to pursue this objective.

Designers can adapt a mature theoretical framework or initiate a new one according to the purpose of the design and features of the setting. For example, in KIE debates, Bell and Linn (2000) utilized the scaffolded knowledge integration framework, which was established through a series of prior investigations. Brown and Campione (1996), in contrast, initiated a new framework in the fostering communities of learners (FCL) project by adapting situated learning theory to support its design purpose—to promote critical thinking and reflection skills.

Principle Two: Set Practical Goals for Theory Development and Develop an Initial Plan

After the purpose has been clarified, designers set specific goals that can be pursued and attained through principled design. Researchers cannot study everything; setting reasonable goals helps to enhance rigor and enforce discipline of the effort (diSessa & Cobb, 2004). The goals are pragmatic in that they aim to address problems in educational practice. For instance, the goals of the Jasper Series (CTGV, 1992b), to improve student ability to solve complex problems, were achieved through "support [for] teachers as they learn to teach with the Jasper materials" (p. 300). Because time and effort may be wasted unnecessarily when significant changes are made late in the process, several design factors (e.g., design setting, available resources) need to be considered early in the process and prior to setting design goals.

Once theory goals have been defined, designers formalize their initial plan. The plan, viewed as an outline strategy designed to achieve the theory goals, will be supported by all design activities. For example, a central innovation in the FCL project is the research-share-perform cycles. All FCL activity structures support these cycles, including guided viewing and writing, consulting experts, and peer teaching (Brown & Campione, 1996). The plan usually contains descriptions or arrangements of the anticipated research phases and steps, the design setting, design team members, research participants, research methods, and other factors considered initially in design. In addition, the plan is flexible to accommodate inevitable refinements necessary in the design processes.

Principle Three: Conduct Research in Representative Real-World Settings

The research problems associated with a given design arise from needs evident in educational practice. The innovations are derived from both the available literature and the analysis of the prospective real-world design settings. The innovations chosen by TSIL, for example, are used to address problems in classroom experiences, such as students' failure to engage in inquiry within available time and resources (Edelson et al., 1999). Thus, contexts in design-based research need to represent rather than oversimplify typical (but complex) settings to the extent possible. Designers need to account for the influence of social factors and dynamics that affect both design participants and the design processes (e.g., school culture, physical characteristics of classrooms). Brown and Campione's (1996) FCL efforts, for example, are situated in elementary schools as students engage in group and independent activities and share their expertise with other participants. The learning environment, as a consequence, is a natural classroom replete with the flow of potentially competing activities and influences typical in everyday schools. At the end of a design cycle, newly generated design principles are connected with the real-world design setting and related literature to ensure their practicality and usability.

Principle Four: Collaborate Closely with Participants

In design-based research, all participants are immersed in the setting and work as collaborators or coconstructors of the design. To ensure the feasibility of the initial plan and improve the design en route, designers consult with teachers and students, remaining mindful of their theory-generating goals as they balance the theoretical and practical. Thus, they neither adopt their clients' values nor impose their own, acting instead as facilitators and adapting to their clients' perspectives, beliefs, and strategies while aligning and extending the design processes (Hannafin, Hill, & Glazer, in press).

To collaborate successfully, coordination of the considerable range of resources and effort is often necessary (Collins et al., 2004). Consequently, designers need to become familiar with the people, resources, and constraints in the learning environment. Familiarization can help to lessen the obtrusiveness of the designer's presence in the learning environment. Moreover, designers need to ensure that their contributions transcend their immediate influence: They are intimately involved in the process, but cannot, themselves, cause research findings, nor can their continued presence become integral to the success of the effort. To the extent the process is managed ineffectively, the extra effort may inadvertently hamper the sustainability and scalability of a design (Fishman et al., 2004).

Consider the challenges involved in studying the cognitive factors affecting sixth graders' use of a Web-based learning environment on geography (WBLE-G). Mr. Stokes, the teacher, thinks that training should be provided to improve his students' map-reading abilities. As the head of the design team, Dr. Carter, however, does not just simply adopt Mr. Stokes's suggestions. Instead, Dr. Carter negotiates with Mr. Stokes to determine whether providing the training suggested is appropriate and consistent with the goals and values of the effort. Dr. Carter may ask design team members to document their influences when they help students to read maps; alternatively, he may determine that the research findings will be confounded by the training provided and fundamentally bias the assessment of knowledge and expertise.

Principle Five: Implement Research Methods Systematically and Purposefully

Researchers use multiple methods, including observations, interviews, surveys, and document analysis (e.g., school policies, student records, and district documents). In addition, needs assessment and evaluation—formative and summative—are often employed in design-based research (Richey et al., 2003). Qualitative documentation methods are often especially useful in design-based research. Hutchinson (1990), for example, noted that both tape recordings and written field notes are widely used to collect original data; sometimes, because of their obtrusiveness, researchers employ them after rather than during implementations. Designers document closely their research procedures, anomalies, and interpretations and understandings using research journals and field notes: The more relevant the available documentation, the greater the decision-altering potential and the more persuasive the descriptions of interventions and findings.

Research methods are also aligned with data analysis and refinement needs of the design. For example, continuous documentation is needed from the outset for retrospective analysis and to generate contextual design principles (Shavelson et al., 2003). Formative evaluation methods are often used when examining intermediate design goals; survey, interview, and observation are helpful to address the theoretical and practical needs of the design.

Principle Six: Analyze Data Immediately, Continuously, and Retrospectively

Analysis is conducted simultaneously with data collection and coding to improve the design and to address theory-generation goals. Generally, two levels of coded data emerge. Level I Data describe the exact research setting and the research processes, such as notes from observations in classrooms, and specific revisions made in the design; Level II Data represent a distillation of Level I Data and are used to explain the design and to construct design principles. Comparative analysis and retrospective analysis are utilized to generate Level II Data by comparing Level I Data with the design context, earlier events, previously collected data, and knowledge in the available literature. Complementary expertise among team members contributes to the retrospective analysis because different interpretations can minimize the bias of a single designer (Cobb et al., 2003).

In the aforementioned WBLE-G design, Dr. Carter may find that 54% of the fourth-grade and 60% of the sixth-grade students use a notebook tool provided in the system (Level I Data). Through retrospective analysis, he compares it with student and teacher evidence gleaned from previous data, revealing that teacher facilitation is important for students to use WBLE-G tools (Level II Data). Based on this analysis, design refinements can be made accordingly.

Principle Seven: Refine Designs Continually

A flexible initial plan is refined iteratively until completion of corresponding design cycles. Refinements, based on Level II Data and constant comparative data analysis, deepen a researcher's understanding of the study context. FCL designers, for example, set age-appropriate goals for children in the design process based on their understanding of children's developmental thinking (Brown & Campione, 1996). Because the design's theoretical framework is valued more than differentiating whether or not a given activity is implemented, refinements are contingent upon the designer's theory-generating goals. Designers refine continually to reach intermediate design goals that collectively address ultimate design goals.

Designers may also reexamine available literature to refine design activities or even intermediate and ultimate theory goals. A new innovation may be introduced en route if proved necessary and feasible. In unexpected situations, designers may refine the design to deal with external or unanticipated influences, such as time constraints or pressure from school principals.

Principle Eight: Document Contextual Influences with Design Principles

Design principles should be context sensitive and of practical importance to other designers. Designers "must be able to specify . . . principles . . . in such a way that they can inform practice" (Brown & Campione, 1996, p.291) and provide principles that are reciprocal and mutually reinforcing; otherwise, they may be perceived to be of limited value for classroom practices. For example, one TSIL design principle is to "identify a motivating context for inquiry early in the design process." This principle is accompanied by descriptions of designers' experiences and strategies in using the principle, and design examples, such as "the selection of global warming as a motivating context" (Edelson et al., 1999, p.440).

Design-based research reports generally include purpose and goals, framework, setting and processes, outcomes, and principles. The purpose and goals section introduces relevant literature related to the design, states the design purpose, and explicates the goals and innovations of the design. The design framework section provides an in-depth description of the framework, its origin and source (i.e., adapted, adopted, or created), and how researchers can achieve their goals through it. The design setting and processes section details both the classroom where design research is conducted and larger system influences (e.g., the environment and culture of the school, student backgrounds), as well as the design phases, processes, intermediate goals, refinements and rationale for refinements, and data collection and analysis methods. Findings are described in the outcomes of the design section, supported by observed results, and linked to the research processes. In the design principles section, principles that transcend the local setting are presented with relevant contextual information; warnings and guidance for appropriate application of these principles may also be provided.

Principle Nine: Validate the Generalizability of the Design

Whereas traditional ID/ISD tends to emphasize the effectiveness of particular approaches to address a local need, design-based research strives to balance local effectiveness with design principle and theory development. Generalizability—the methods used, refinements made, and innovations introduced to support the purpose and theory-generating goals of the design—must be verified according to the theory goals of the design and discipline requirements of the research. Researchers need to optimize a local design without decreasing its generalizability, because effectiveness is a function of both success in addressing local needs and the applicability of design principles to other settings. For instance, through collaboration with teachers, researchers may recognize teacher concerns and enact refinements consistent with the immediate and ultimate research goals. These refinements, in turn, may improve the immediate effort of the local design and subsequent collaborations, but the idiosyncratic nature of the concerns and refinements may pose problems in different settings where the design might be implemented.

CHALLENGES OF DESIGN-BASED RESEARCH FOR TELE DESIGN

As an emerging methodology, design-based research has both advantages and limitations. Four issues are particularly challenging: (a) immature methodology, (b) applicability and feasibility, (c) paradigm shift, and (d) data utilization.

Immature Methodology

Methodological development is needed to both enhance rigor and account for the importance of local context (DBRC, 2003). For example, it is difficult to determine whether to continue or abandon an iterative design, because standards do not exist to judge its effectiveness (Dede, 2004). Moreover, even where the design is proved effective in a local context, it may prove difficult to determine if valid design principles can be generated. An otherwise effective design, capable of generating useful principles, could be discarded because it was ineffective in a specific local context.

Next, design-based research comprises a collection of multiple research frameworks that are internally consistent but assume many forms and reflect varying levels of discipline and rigor. Many differences exist between and among these frameworks. For example, during developmental research, researchers may or may not be involved in different aspects of the research processes (Richey et al., 2003); in design experiments, researchers are involved throughout (Cobb et al., 2003). Thus, while certain conceptual similarities exist, the methods themselves may differ in fundamental ways, making it difficult to identify a specific methodology to guide research and design.

Applicability and Feasibility in Current Education System

The accountability culture of present-day research and practice emphasizes methodologies that are deemed scientifically valid, that is, they demonstrate particular discipline and provide particular kinds of evidence. Design-based research may not satisfy the policymaker's requirement for scientifically based research (Cobb, 2001). The premium on compliance with accepted methods and measures may limit preemptively funding prospects for design-based research and development, discouraging its use and limiting its potential in otherwise ideal circumstances. In addition, the presence of researchers in the classroom throughout the process may be perceived as a distraction or intrusion rather than a contribution to local efforts. Teachers and administrators may prefer to use already developed products and approaches rather than to become deeply involved in their creation. Thus, pragmatic and political constraints may hamper or preclude design-based research approaches in many settings.

Paradigm Shift

Design-based research methods both share and extend conventional evaluation approaches. In some cases, the extensions are significant and represent fundamental changes in goals, scope, and methodology. For example, TELE designers are generally very familiar and comfortable with formative evaluation methods, but less familiar and comfortable with generating new theories and generalizable design models. Additionally, because designers work intimately with participants, unanticipated influences such as Hawthorne effects may result from their pervasive presence. The designer's influence—undocumented in the research process—may inadvertently affect research outcomes. This paradigm shift requires changes in both how designers plan and implement system approaches and how they interact with participant-collaborators.

Data Utilization

Design-based research has been characterized as over-methodologized—only a small percent of the data collected are used to report findings (Dede, 2004). Design-based research requires documenting the whole design process and using multiple research methods in real-world learning environments. The data are typically extensive and comprehensive, requiring both extended time and resources to collect and analyze (Collins et al., 2004). However, because time and resources are often limited, large amounts of data are routinely discarded, and research quality may be influenced negatively. If made accessible to other TELE researchers, however, "lost" data could both save time and improve quality. The gap between the methodology used to collect data and its meaningful utilization needs to be decreased.

CONCLUSIONS

Design-based research and TELE designs are reciprocal and, thus, need to be interdependent. In order to stimulate contextually-sensitive practices of learning and instruction in the design and implementation of TELEs, practical, detailed, and contextual advice is necessary. Design-based research, as a pragmatic methodology, can guide TELE designers while generating practical knowledge to be shared among a broad design community. Conversely, TELE design theories, models, and procedures need to ensure that design-based research methodologies can be made operational, formalized, and systematized.

Design-based research may not be applicable for TELE designs valuing local efficiency and economy over validity, theory refinement, and generalizable design principles. Nor are design-based approaches likely to fit all the varied needs and requirements of clients, policymakers, and designers. Design-based research advances instructional design research, theory, and practice as iterative, participative, and situated rather than processes "owned and operated" by instructional designers. They are neither easy nor intuitive to implement; indeed, they require a shift in perspective of the traditional ID/ISD enterprise and a sustained commitment to advancing theory and practice. TELE designers need systemic guidance to identify suitable interventions, integrate diverse research methods with design processes, implement designs appropriately, and document their effectiveness and impact. Future research should help to document both the effectiveness of local designs and the generalizability of research results, and ultimately improve applications of design-based research in TELEs. □

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