Cyberinfrastructure for Design-Based Research: Toward a Community of Practice for Learning Scientists

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Abstract: This symposium is part of an NSF project to help The Learning Sciences community collaboratively envision a cyberinfrastructure for design-based research (DBR). Like numerous others before us, we argue that the educational research community would be well served by a mutually created cyberinfrastructure that would encourage and support engagement by multiple design-based researchers in sharing knowledge and working toward answers to important theory-driven research questions, moving our field toward a "bigger science" approach. The vision is one in which junior and senior scholars set collaborative research agendas and establish common protocols and systems to support systematic collaborative archiving, sharing and analysis of multi-modal data. This symposium offers critique, reflection, and concrete proposals for design, helping demonstrate the possibility of implementing this idea and moving it toward becoming reality.

Chair's Introduction
Sharon J. Derry

The Problem
Design-based research (DBR) is a mixed methods approach that involves the iterative and systematic design, development, and study of theoretically guided educational innovations in their implementation contexts (Barab & Squire, 2004; Collins, Joseph & Bielaczyc, 2004; The Design-Based Research Collective, 2003). Although DBR is in early stages of development as a methodology and paradigm, its popularity among researchers, funding agencies, and journals is growing and spawning lively academic debates (e.g., Anderson & Shattuck. 2012; e.g., Dede, 2004; McKenney & Reeves, 2013). In a penetrating commentary on the special issues devoted to DBR in *Educational Researcher* (2003) and *Journal of Learning Sciences (2004)*, Dede (2004) worried that discussions had pushed the boundaries of DBR too far, rendering a sort of "Swiss Army Knife" for scholars trying to find a tool for too many purposes. He encouraged instead a bounded conceptualization (e.g., Collins, Joseph & Bielaczyc, 2004), giving focus to the kinds of questions DBR studies can reasonably address: When is an initial implementation of an educational innovation successful enough to merit further investment in perfecting the innovation? When is it successful enough to warrant implementation and testing on a large scale? What generalizable knowledge about the conditions and reasons for success can be gleaned from a DBR study, and how can we use this knowledge to support effective translation of a successful innovation into a range of new contexts? Our symposium addresses whether the DBR research enterprise can be improved and leveraged to help discover generalizable scientific knowledge of the type needed to develop successful educational innovations and understand them well enough to support their full-scale implementation.

Whether general scientific knowledge can be harvested from DBR is, however, a subject for debate. DBR crafts innovations by working within educational contexts that represent a complex mesh of goals, content, technology use, principles of learning, teaching methods, and accountability systems that must be woven together and shaped to a particular environment. Because any measure of success reflects the whole of the interacting variables that comprise the complex system, it is very difficult to isolate stable causal mechanisms within it or to translate lessons learned into other grade levels, students, schools, subject matter, types of technologies, etc. (Fadel and Lemke, 2006). For this reason, Anderson and Shattuck (2012) speculate that DBR may be more suitable for making and sustaining improvements in small-scale systems rather than contributing to large-scale and far-reaching systemic reform.

Yet DBR is increasingly called upon to fill an important niche in the array of methods now used to improve educational practice and create generalizable principles about it (Collins et al., 2004). For example, The Institute for Educational Studies (IES) currently funds ideas for educational innovation at several stages of increasingly larger funding, with DBR often the preferred approach for early and middle phases of an innovation's history. DBR in these phases helps perfect and test a theoretically designed innovation, providing evidence pertaining to its local success as well as implementation experience to support an informed translation, if warranted, into increasingly larger-scale contexts. Eventually, randomized experimental trials may produce generalizable judgments about an innovation's effectiveness and, consequently, about the theory of learning upon which the implementation project was based. In this model, DBR, hypothetically, contributes to theory from a pragmatist's perspective: Theories about *learning in context* are proposed and evolve through their various instantiations within a DBR research program. Experimental trials then produce confirmatory evidence, offering generalizable judgments about an innovation's effect as well as evidence supporting the pragmatic value of the situated learning theory upon which the implementation was based.

However, this passage to educational research Nirvana through DBR is a slow, methodic, expensive pilgrimage and, as recent discussions of DBR acknowledge, fraught with challenges. In fact, reviewers of DBR progress have been hard-pressed to identify any such completed journeys. But before considering those challenges and how to address them, it may be worth a brief digression to consider an alternative case, that is, the result of a lengthy educational research enterprise that did not build on a meticulous build-up of theory and implementation knowledge that DBR research strives to achieve. Consider, for example, the hundreds of studies of the effects of technology that have been conducted across a wide variety of educational settings over the last several decades. Many studies have been aggregated in several influential reports—e.g., ACT Policy Report: Evaluating the Effectiveness of Technology in Our Schools, 2004; Cisco Systems/Metiri Group Technology in Schools: What the Research Says, 2006; Milken Exchange on Education Technology, 1999; and the National Middle School Association Research Summary: Technology and Learning, 2007 (Fadel & Lemke, 2006; Noeth & Volkov, 2004; Schacter, 1999). These reports consistently acknowledge that using technology provides a small but significant increase in learning across all uses in all content areas, but they offer little guidance for implementation and include substantial caveats. Has a torrent of research on educational technology produced only a trickle of knowledge?

One problem relates to the inadequacy of the research methodologies employed to reach conclusions. "Most studies on the effect of educational technology on learning are correlational studies," wrote Fadel and Lemke (2006). "Although such studies suggest what is working, they do not control for confounds that may provide alternate explanations for results." Also, perhaps we have been mired too long in fruitless atheoretical research that engages experimental and statistical control to focus on effects of single features, such as "uses technology," that are largely meaningless when considered separately from the complex, interacting factors comprising an entire ecology of teaching and learning. "Results and conclusions must be considered in the context of the interdependent set of variables in which the use of technology is embedded" (Fadel & Lemke, 2006). The unfolding DBR narrative is largely a research community's response to this realization, and the story of its aspiration to carry out credible, theoretical scientific research of pragmatic significance in complex natural settings.

Unlike the experimental psychologist, who controls all aspects of an environmental recipe including the specific added ingredients associated with causal hypotheses about cognitive mechanisms, the DBR researcher eschews introducing artificial controls into educational environments. What DBR teams do is infuse an established educational ecology with new ideas and creations (an 'innovation'), having in mind some theoretically derived hypotheses about how such infusions will alter the landscape to effect positive learning outcomes. Then begins the business of systematically studying that dynamic landscape in action, perhaps before but certainly during and after the innovation is introduced, searching for clues that will lead to an understanding of how the innovation and the ecology coalesce to effect learning. Researchers crisscross the landscape to collect data for analyses based on their hypotheses and a priori research questions, but they also attempt to capture other interactions that emerge as interesting, to increase the likelihood of fruitful unanticipated discoveries (e.g., Derry et al., 2010). In this effort to leave no potentially important stone unturned, DBR researchers typically document an innovations' development and implementation history with detailed descriptions of situational contexts, rationales for designs and design changes at different phases, and learning and process outcomes. The overwhelming result is that every DBR project produces a substantial data collection. A widespread criticism and controversial issue dogging DBR is that it typically generates volumes of data that are never used.

One reason for this current state of affairs is that there are few agreed-upon standards, goals or structures to guide DBR scholars on what data to collect and archive. In addition to being unwieldy in size, DBR datasets are shaped in content and structure by whatever unique research questions and systems for data collection and archiving that an individual project or research group devises. Uniquely structured, unpublished datasets cannot be accessed or utilized, without great difficulty, by researchers and educators from outside the

project. It is even less likely that such datasets will be combined and aggregated for analytic purposes. In fact, the DBR research enterprise, in all respects ranging from the formulation of research questions to the archiving of data, is so fragmented that sharing and advanced data mining, which could address important theory-based questions across many projects, are difficult to impossible.

In discussing both promises and threats to the impact of "design-based implementation research," Penuel, Fishman, Cheng and Sabelli (2011) argued that it is time to develop DBR as a more systematic form of inquiry and practice. They believe the DBR community must develop better norms and practices for theory development and for specification and testing of claims. They also called for developing standards regarding how evidence is used to guide design refinements, and practices for incorporating into studies multiple points of view and conflicting interpretations of data. Finally they suggested standardized use of design rationales in the manner that professionals in fields such as architecture, urban planning, and software engineering articulate such rationales to clarify the purposes and history of the design process, and to help them reflect on and modify designs. Design rationales could serve to make public the ways that educational teams employ evidence to resolve conflicts, weigh competing approaches to improvement, and identify new areas of focus for their work. Penuel et al. (2011) echo similar appeals by other analysts of DBR research. Collins, Joseph and Bielaczyc (2004), recently cited in Anderson & Shattuck (2012), previously advanced the idea of a DBR infrastructure to support data archiving, sharing and collaboration. Noting that design experiments produce large amounts of data that go unanalyzed, they called for an infrastructure to allow researchers from outside the original design team to access and analyze the data collected in large studies. Not surprisingly, Anderson & Shattuck's recent review (2012) failed to uncover any evidence of such sharing currently taking place. Such sharing would require the DBR community to have standard protocols and systems for archiving of data in a format that supports multiple forms and levels of access, sharing and analysis, while adequately protecting the privacy and identities of human subjects.

Purpose of Symposium

The organizers of this symposium believe the learning sciences community would be well served by mutually creating an infrastructure to encourage and support collective engagement by multiple design-based researchers in working toward answers to important theory-driven research questions, moving our field toward a "bigger science" approach. It is in this spirit that we reach out to members of this community to join with members of other relevant fields, such as computer science, in an effort to design, build, support and participate in a mutually established cyberinfrastructure and user community for DBR. This symposium would continue the organizers' NSF-sponsored effort, begun at a recent CSCL 2013 workshop, in which we vetted one concrete proposal to organize a group of participating researchers around designing and using a common suite of Internet-based workflow visualization tools that would impose flexible but agreed-upon standards for data collection and ways of working (Hackbarth, 2011; Hackbarth, Derry, Eagan & Gressick, 2010). In this ICLS symposium we call for additional proposals as well as reflections and critiques on proposals put forth and the enterprise in general. One question that emerges from our work so far is whether a primary goal of this endeavor should be to support the work of junior scholars. These are the issues that the collective presentations in this symposium, which was designed to include scholars at various career stages, will address. This goal fits well with the stated conference theme to "focus on practices that pertain to how we organize our own work as learning scientists: the practices for analyzing and modeling learning across settings and time and the practices for designing for scale and sustainability."

The presentations that follow each bring a unique perspective in discussing how a well-developed line of inquiry might inform the design of a DBR cyberinfrastructure. Hackbarth's presentation will supply an "object to think with" in describing how developing data analytic tools based on workflow visualization provides one feasible way to proceed. Richard Lehrer will contribute years of experience conducting design-based research in schools by sharing his team's practice of creating "design documents." In discussing the strengths and limitations of design documents, he suggests that the next phase of DBR must focus on instrumentation to permit tracking of design trajectories at a larger scale, so that theory development can follow. Katerine Bielaczyc will draw from cases of distributed DBR with Knowledge Building Communities to examine the usefulness of the Social Infrastructure Framework as a basis for defining data categories and metadata tagging within a cyberinfrastructure. She will also consider how a cyberinfrastructure enterprise could support early and low-resource researchers. Gonzalez and Sandoval will describe a needs analysis for graduate training of design-based researchers, examining what features of a cyberinfrastructure project are needed as support this effort. Discussant Allan Collins will offer an integrative commentary on these proposals and the enterprise in general.

In 2004 Chris Dede challenged the DBR community to engage in an evolutionary dialogue about the purpose and processes of DBR that would define DBR in a realistic way. He was not optimistic that the community would be able to do so at that time. But perhaps the time is now.

Workflow, Information Visualization, and the Potential of Cyberinfrastructure to Manage Design Based Research

Alan J. Hackbarth, Sharon Derry and Sadhana Puntambekar

According to the Design-Based Research Collective (2003), the critical characteristic of design based research is that the central goals of designing learning environments and developing theories or "proto-theories" of learning are intertwined. Development and research takes place through continuous cycles of design, enactment, analysis, and redesign, and research must account for how designs function in complex authentic settings – not only in terms of success or failure, but also in terms of interactions that refine understanding of the learning issues involved. One needs a well-developed profile of an implementation in order to analyze a design in terms of its key elements and their interactions, but this is challenging because of the number of variables to account for and the diverse people involved at different levels of design implementation. Given this complexity, design researchers usually end up collecting large amounts of data, more data than they have time or resources to analyze.

Addressing these issues, Hackbarth will discuss the NSF-sponsored work our research team is undertaking to co-opt and develop data-analytic tools into a cyberinfrastructure that gives researchers leverage to organize and access layers of complex data in a way that facilitates analysis and deeper understanding of learning in authentic settings. This work began with development of the Workflow Visualization System (WVS) (http://vmc.wceruw.org/workflow/workflow.html), a prototype that utilizes workflow concepts from business and science, information design principles (i.e., Tufte), and web interactive tools to document the design and implementation of units of instruction. The WVS was vetted at a workshop of DBR researchers at CSCL 2013 in order to stimulate discussion of the pragmatic challenges of doing DBR and suggestions/specifications for a cyberinfrastructure tool that will address the challenges. Issues raised at the workshop included the need for an interface that provides: access to and makes clear the rationale and goals of a design to all parties (e.g., researchers and teachers); flexibility to document a wide range of elements and structures of a design and their interrelations, and to document design changes that occur during implementation; reduction in time-consuming processes of data collection, archiving, and retrieval; and ways of connecting designs and data to questions/propositions/theories.

The emerging tool is a synthesis of course management functionality from Moodle and semi-automated visualization functionality from the WVS. A user will have the ability to write a specification of the research project, including hypotheses, assumptions, theoretical framework(s), research questions, context, and so forth, and create any number or types of fields to collect data about a designed intervention. Researchers will then be able to use a drag-and-drop tool to create a multi-layered visualization of the intervention and associate data fields to each part of the visualization. (See Figure 1.) They will also have the ability to annotate each part of the visualization. As a designed intervention takes place, learner-generated data will be added to the visualization. All information and data will be accessible from the visualization by mouse-overs or clicks on icons. The overall purpose of the tool is to make visible in one place the interconnections among elements of the intervention and provide access to data about, or generated from, each element of the intervention.

This presentation will describe and show examples of our emerging cyberinfrastructure tool for managing the processes of DBR, and how it may contribute to codifying standards and moving DBR from a collection of methods to a methodology.
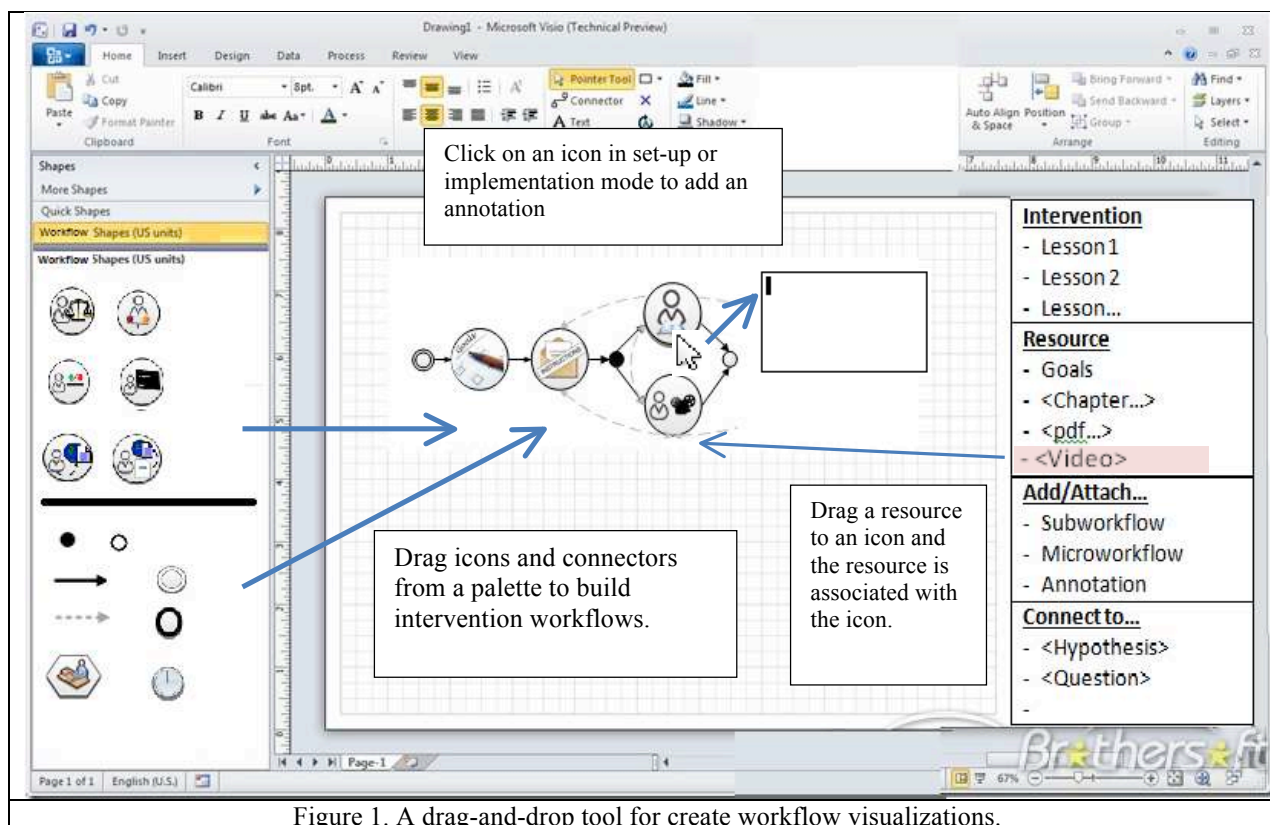
Figure 1. A drag-and-drop tool for create workflow visualizations.

Knitting Designs Across Venues and Contexts
Richard Lehrer

Design-based research is now acknowledged as a useful and powerful framework for generating and testing "modest" theories of how particular innovations function in particular settings. Yet there is a persistent press to elevate designing to the status of method, with attendant clear guidelines and prescriptions for practice. This press for method may have the unintended consequence of exchanging the flexibility and responsiveness essential to the conduct of design-based research for the apparent rigors of method. A more productive elaboration on design-based research would be to develop tools that make the process and products of design more transparent and that are useful to the process of design. First steps in this direction have been taken, as indicated by the participants in this symposium. For our part, we have established a practice of constructing "design documents" that describe essential elements of a learning ecology and the ways in which these elements are orchestrated to increase the probability of learning in particular ways for particular purposes. Design elements include: 1. the nature of the tasks/problems that are either posed to participants or are likely to be generated by them; 2. the representational and related symbolic systems that participants either appropriate or invent; 3. the material means of production available; 4. the modes and means of argument that are privileged in the system, and 5. the activity or participant structures that are likely to influence exchange among participants. Interactions among these elements of design constitute prospective mechanisms of learning, and these interactions are intentionally supported in classrooms or other deliberately designed ecologies.

Design documents also describe the nature of evidence about and for learning. Reflecting on our practice, design documents appear adequate for rendering forms and spaces of learning that are characterized by modest scope—those that can be traversed within days or perhaps a few weeks of instruction. For more ambitious efforts, such as designing learning progressions or other endeavors of more significant scope, design documents are difficult to sustain. One problem is that efforts of larger scope—as in longitudinal research extending over years, or coordinating design of professional development and its temporal patterns with that of students—require tools that allow one to visualize relations between otherwise distinct design efforts. Moreover, designs for learning that are extended in time require ways of tracking prospective trajectories of change at individual and collective levels. In my talk I will suggest that the next phase of design-based research needs to be one focused on instrumentation, and that instrumentation needs to lead so that theory development can follow.

Using the Social Infrastructure Framework to Guide Data Collection and Tagging Metadata in Building a Cyber-infrastructure for Design Research

Katerine Bielaczyc

In carrying out design research involving technology-based tools, it is critical to extend the design process beyond the tool itself to consider the elements of the broader classroom learning environment. The social structures of a classroom play a key role in such a design. The Social Infrastructure Framework (SIF) specifies a set of critical design variables concerning classroom social structures (Bielaczyc, 2006). The top-level variables include:

- *Cultural Beliefs*
- *Practices*
- *Socio-Techno Spatial Relations*
- *Interaction with the "Outside World"*

In turn, each top-level category has sub-variables. For example, Practices includes sub-variables such as *the associated participant structures of students* and *the coordination of on-tool and off-tool activities*.

In creating a cyber-infrastructure for Design Research, the SIF can be used to guide both (a) the data collection activities of distributed researchers working toward common design goals, and (b) the tagging of metadata in storing the data collected across multiple projects. Looking at a variety of classroom implementations through the lens of the SIF would make such design decisions explicit and permit design elements across these settings to be classified into a common form, providing a systematic basis for comparisons and contrasts.

Further, because these data archives would provide a rich representation of various classroom social structures, researchers not involved in the original research may be able to study questions of their own choosing concerning the social structures in a particular setting. That is, through tagging meta-data across multiple design experiments, they may address new questions beyond those posed by the original researchers. What an educator, anthropologist, cognitive psychologist, or media designer will see when they look at the data from a particular design experiment or across a variety of design experiments will be very different. When different eyes look at a design, it provides a kind of triangulation that we do not often find in reports on design experiments. Instead of analysis using different sources of data, this kind of triangulation would provide different theoretical perspectives on the same data.

In addition, such an archive would allow researchers, who are just starting their careers or who are located in places with few resources, to carry out their own research with a rich data source. This would give doctoral students the possibility of carrying out design research with a deep disciplinary focus. Their analysis would be set against the multi-disciplinary analysis of the original researchers, which would promote learning of the broader issues, while maintaining an emphasis on the methodological concerns of their own discipline. Their training would embody disciplinary analysis in a multi-disciplinary context, and hence they might get the best of both approaches to training.

In the presentation, I will discuss various issues that arise in using the SIF to guide both data collection and the tagging of metadata. I will draw from various cases, including the corpus of classroom data collected by researchers involved in distributed design research with the Knowledge Building Communities model (Scardamalia, 2002; Scardamalia & Bereiter, 2006).

Learning to do Educational Design Research: A Needs Analysis

Carlos Gonzalez and William A. Sandoval

In the writing on educational design research that has blossomed over the last decade, there is little articulation about how to train new researchers to conduct educational design research. We present a needs analysis for graduate training in educational design research, derived from a synthesis of available writing on design research as a method and our own experiences in doctoral training. The analysis identifies areas where newcomers to the learning sciences require training to conduct design research that moves the field forward, while leaving open the questions of how to best provide such training. Obviously, learning to do design research entails overlaps with graduate training in educational research more generally, including selecting good research questions, reviewing relevant literatures, and methods and research design. We see design research as complicating this research training in two respects. First, there are the particulars of work that change through *phases* of educational design research, from problem analysis, design, and enactment, through retrospective analysis. Each phase carries particular training demands. For example, problem analysis typically requires the synthesis of literatures, often across a range of disparate fields, to understand the background to some learning problem and previous efforts to solve that problem. It may further require a local needs analysis in the specific intended context of work. Similar demands, unique to design research, arise in each phase.

A second respect in which design research requires particular training is related to *trajectories* of design research. The majority of writing about design research assumes a linear trajectory of increasing scale, akin to clinical trials in medical research and familiar to educational intervention research generally. Yet, an analysis of design research as it has been carried out over the last couple of decades reveals a diverse family of approaches to design research, with their own particular trajectories suited to the pursuit of particular sorts of questions. Important and notable design research is best characterized in terms of increasing depth rather than scale, and this difference in focus carries implications for the research methods one uses across design studies. These families of design research may differ in their emphasis on the joint goals of understanding processes of learning and teaching and understanding innovation, and such emphasis can change across a trajectory of work. These demands require new design researchers to be well trained in a variety of qualitative and quantitative methods in ways that are linked to phases and trajectories of design research. We will present the details of our needs analysis in terms of training requirements for doctoral training. The analysis will suggest features of a cyberinfrastructure that could support such training.

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