A Cyberinfrastructure for Design-Based Research:
A Collaborative Design Project Proposal

WCER Working Paper No. 2018-14
December 2018

Sharon J. Derry
University of North Carolina-Chapel Hill
derry@email.unc.edu

Alan Hackbarth
University of Wisconsin Colleges

Sadhana Puntambekar
University of Wisconsin–Madison

Suggested citation: Derry, S. J., Hackbarth, A., & Puntambekar, S. (2018). *A cyberinfrastructure for design-based research: A collaborative design project proposal* (WCER Working Paper No. 2018-14). Retrieved from University of Wisconsin–Madison, Wisconsin Center for Education Research website: http://www.wcer.wisc.edu/publications/working-papers

Abstract

Like numerous others before us, we argue that the educational research community would be well served by a mutually created cyberinfrastructure that encourages and supports engagement by multiple design-based researchers in working toward answers to important theory-driven research questions, moving our field toward a “bigger science” approach. We reach out to members of the educational research community to join with members of other relevant fields, such as computer science, to design, build, support and participate in a mutually established cyberinfrastructure and user community to support design-based research. We seed the discussion by offering a concrete initial proposal to illustrate the possibility of implementing this idea.

A Cyberinfrastructure for Design-Based Research:
A Collaborative Design Project Proposal

Sharon J. Derry, Alan Hackbarth, and Sadhana Puntambekar

Design-based research (DBR) refers to 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; Reeves, Herrington, & Oliver, 2005). 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 comments that follow pertain mostly to these last two questions regarding how the DBR research enterprise might be improved and leveraged to help discover generalizable scientific knowledge needed to support full-scale implementation of successful educational innovations.

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 & 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. 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). These reports consistently acknowledge that using technology provides a small but significant increase in learning across all uses in all content areas (Fadel & Lemke, 2006; Schacter, 1999; Noeth & Volkov, 2004), 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 constituting 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.

The Promise and Problems of Design-Based Research

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 no 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), as 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 and 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.

It seems, therefore, that the educational research community would be well served by mutually creating an infrastructure that would 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 this spirit that we reach out to members of the educational research community to join together with members of other relevant fields, such as computer science, to design, build, support and participate in a mutually established cyberinfrastructure and user community for DBR. 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. Perhaps the time is now.

The Workflow Visualization System (WVS): A Design Proposal

We seed the discussion by offering a concrete initial proposal for designing a cyberinfrastructure. Based on the dissertation research of Alan Hackbarth (Hackbarth, 2011), this proposal is offered as a feasibility demonstration and conversation starter rather than a final solution path.

Conceptual Foundations

DBR is conducted within the "blooming, buzzing confusion" of classrooms and other authentic learning environments (Brown, 1992, p. 141). Many variables are at play within design experiments, including some that are not anticipated and cannot be controlled (Collins, Joseph, & Bielaczyc, 2004); e.g., events such as the interrupted availability of a computer server or the timing of a spring break. Yet it is important when doing DBR to identify the critical variables of a design and how they fit together (Collins et al., 2004). In order to evaluate an implementation of an instructional design one needs to analyze each case in terms of its key elements and their interactions. Some elements will be implemented more or less as designers intended, some will be changed to fit circumstances, and some will not be implemented at all. A profile of how each critical element was implemented and how they worked together toward the designer's goals is needed. Further, because each variable is part of a systemic whole it may be impossible to change one aspect of the system without creating perturbations in others (Brown, 1992). These perturbations and their effect on student learning need to be identified and accounted for in iterative cycles of design, enactment, analysis, and redesign in authentic settings that constitute DBR (Barab & Squire, 2004; Collins, 1992).

It is important to document designs at a level of detail appropriate to the research questions and design goals of the experiment, and critical to record all major design changes at that level. Major changes mark the borders that differentiate one phase of an implementation from the next (Collins, 1992). A well-documented design history that includes well-archived, accessible student outcome data can provide evidence for causal impact on measured student outcomes. It facilitates theory building that impacts student learning and allows research audiences to evaluate the credibility of design decisions and the quality of lessons learned from the research (Barab & Squire, 2004). However, in the process of documenting and studying design, researchers collect large amounts of data throughout an intervention—e.g., video, student produced artifacts, and activity logs from online interactions—often more data than they have time or resources to analyze (Barron, 2007; Brown, 1992; Collins et al., 2004). To ensure that design researchers maximize their use of collected data to develop rich representations of critical variables and their interactions in a learning environment, analytical procedures that organize, document, and archive data in an easily accessible format that facilitates more efficient deeper analyses are needed (Merriam, 1988, p. 124). Such procedures also maximize potential for access and reuse of instructional designs, assessments, and learning outcome data by a broader research community.

Intermediate Representations

Barron (2007, p. 178; as cited in Derry et al., 2010) discussed the emergence and value of *intermediate representations* as a response to the need for better analytical procedures for complex field-based datasets. Intermediate representations that organize and display data are important for identifying what to analyze and for understanding patterns within and across segments of field data. Barron identified several examples of intermediate representations that are either created during data collection or are derived from an initial *macro*-analysis of field records. These include *content logs*, which are often created in the form of field notes that index data while it is being collected; *table-based flow charts* that chronologically catalog events of a group or individual learning experience and highlight significant events for deeper analysis (Ash, 2007); *descriptive diagrams* of interactions that illustrate participants' relations to one another and resources in an informal learning situation (Angelillo, Rogoff, & Chavaj, 2007); and *conversation maps* that show the flow of discourse in a learning situation (Barron, 2003). Intermediate representations provide organizing structures that help research teams develop a sense of the corpus of data and facilitate the selection of episodes for further detailed analyses (Barron, 2007, p. 179).

Macro-level intermediate representations. Macro-level intermediate representations satisfy a core characteristic of DBR: that the goal of developing sharable, adaptable learning interventions with practitioners is intertwined with the goal of developing theories of learning (Collins, 1992, The Design-Based Research Collective, 2003). Standardized systems of intermediate representation could facilitate DBR by providing users with a means of representing both major elements that frequently appear in designs across contexts, as well as their major interrelationships, in much the same way this has been accomplished in physical sciences (De Roure, Goble, & Stevens, 2007). Wide adoption of an adaptable but standardized representational system would allow researchers to hypothesize about, even conduct virtual experiments on, the learning effects of including, rearranging, or redefining the contents of elements across contexts.

Visualization. In writing about information processing in the world of business, David Tegarden (1999) observed that decision makers suffered from information overload while at the same time underutilizing large amounts of data. Because the majority of the brain's activity that deals with processing sensory data deals with analyzing visual images, he argued, visualization technologies help resolve this dilemma. Humans naturally look for structure, features, patterns, trends, anomalies, and relationships in data (Grinstein & Ward, 2002). A visualization harnesses the perceptual capabilities of the human visual system and allows a viewer to (a) examine a large amount of data, (b) keep an overview of the whole while pursuing details, (c) keep track of many things by using the display as an external working memory, and (d) produce an abstract representation of a situation through the omission and recoding of information (Card, 2008). Larkin and Simon (1987) argued that diagrams can be superior to written representations because they can (a) group related information together, (b) use location to aid in information search, (c) aid in many perceptual inferences, and (d) support efficient computational processes. Visualizations amplify cognition by reducing the search for information, enhancing the detection of patterns, enabling perceptual inference operations, using perceptual attention mechanisms for monitoring, and by encoding information in a manipulable medium (Card, 2008). Tegarden (1999) cautions that the purpose of visualization is not to replace empirical analysis, but instead to focus such analysis by exploiting the human visual system to extract information from data that allows decision makers to determine areas of interest or promise where further exploration should be done.

A Visual Workflow System (VWS) for DBR

One feasible approach is to construct a system that uses visual workflow to construct intermediate representations that help structure research and sharing of research about instructional interventions (Hackbarth et al., 2010). This approach has provided a valuable support for our own DBR, although because we lack the technological tools that automate our approach, our current method is time consuming. It is also limited in that there is no automated mechanism that allows researchers to easily annotate elements of an intervention; for example, noting the rationale for the inclusion of an instructional resource or adding a reflective note about an idea for lesson modification. However, a fully developed VWS would add these functionalities, making it efficient for helping DBR researchers archive, document, and explore data collected from interventions. It would also make the data easily available and browsable by other educators and researchers.

Widespread adoption and use of such a system is plausible because many learning environments share key structural similarities. They (a) set learning goals and coordinate a series of activities to accomplish those goals, (b) design or identify ways to collect data on student learning to assess accomplishment of goals, (c) relate resources (e.g., readings, demonstrations, video) to learning activities, (d) organize workspaces, and (e) scaffold student interactions during activities. Based on feedback from case studies conducted with research partners at Rutgers University (Hackbarth, 2011), we successfully applied a *workflow* metaphor to create understandable, sharable, multilevel standardized *intermediate representations* of educational interventions that show (a) the essential flow of lesson tasks, (b) the relation of resources to tasks, (c) the outcomes of tasks, including evidence of student learning and performance, and (d) details on how learners are expected to and/or actually do interact with lesson resources and one another.

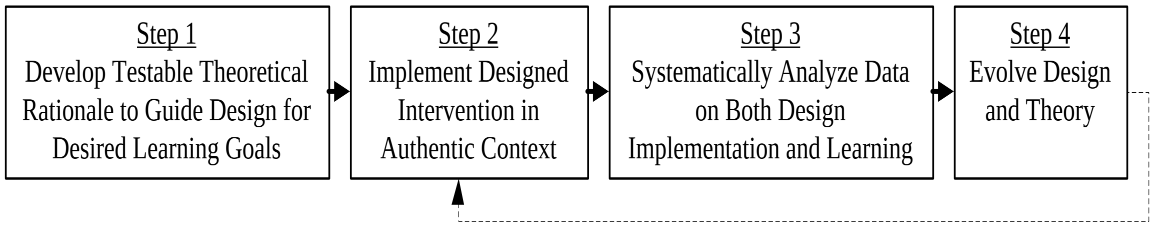
The Workflow Management Coalition defines *workflow* in a business environment as "[t]he automation of a business process, in whole or part, during which documents, information, or tasks are passed from one participant to another for action, according to a set of procedural rules" (Hollingsworth, 1995). Broadly stated, a workflow "participant" (i.e., human being or technological tool) receives data in some form as *input*, acts upon it with a *process* that may or may not be fully scripted in advance, and its *output* may become or inform input for the next "participant." Although contexts and interactions in the world of business are generally more controlled and predictable than in education, a business processes metaphor has utility in describing the design and implementation of an educational intervention: instruction can be generally described as a series of processes where documents, information, or learning tasks are passed to learners with the intent that they will be processed by some action and (measurable) learning outcomes will be produced.

In applied science, workflows are not simply digital data objects, *they capture pieces of scientific process*—they are valuable knowledge assets in their own right because they are graphical representations of "know-how" that is often tacit. The idea of *reuse* (De Roure et al., 2008) suggests that there may be a standardized way of doing particular processes where the inputs change but the process, or the rationale for the process, remains consistent across implementations. Reuse can occur effectively at multiple levels: a scientist can reuse a workflow with different parameters and data, fragments and patterns of a workflow can be reused to support science outside their initial application, or they can provide a means of codifying, sharing, and spreading the workflow designer's practice. Parallels can be drawn to teachers or designers who introduce new inputs (e.g., data or concepts from instructional materials) while reusing a pedagogical process (e.g., a problem-based learning activity) from lesson to lesson, and to share adaptable interventions.

Inspired by increasing use of workflow languages to capture, document and control processes in both applied science research and business applications (Ailamaki, Ionnidis, & Livny, 1998; Cardoso, Bostrom, & Sheth, 2004; Ludäscher et al., 2005; Mentzas, Halaris, & Kavadias, 2001), and by trends toward reuse and recombination based on standard workflows and shared databases in the physical sciences (De Roure, Goble, & Stevens, 2007; Gil et al., 2007), we explored the potential of workflow visualization to help document instructional activities offered in an online learning environment for the purposes of (a) supporting DBR related to incremental development of the activities and related theories that propose causal connections between design features and student learning outcomes; and (b) sharing adaptable, tested workflows of enacted educational interventions with other researchers and teachers.

DBR itself can be described hierarchically as a workflow, as summarized in Figure 1.

***Figure 1*. Steps in a design-based research workflow**



The implementation of a designed intervention at, for example, Step 2—a thoughtfully orchestrated collection of learning activities—can be unpacked and represented as a workflow visualization having varied levels of detail. At an intermediate level that we call the *macro-workflow* or *lesson* level, workflow visualizations facilitate (a) identifying and organizing (thereby helping to gain control over) many types of variables and learning outcome data that intersect during an educational intervention, and (b) sharing adaptable educational interventions that produce known outcomes with other educators who can modify the general framework represented by the workflow expression to accommodate local contexts. Additional levels might provide progressively finer-grained representations that both constitute and facilitate deeper analysis (Step 3) in the iterative process of DBR that may include both hypothesis-driven and exploratory studies of learning.

Workflows feature visual representations of data. Edward Tufte (1990. p. 33) notes:

> We envision information in order to reason about, communicate, document, and preserve [that] knowledge—activities nearly always carried out on two-dimensional paper and computer screens. Escaping this flatland and enriching the density of data displays are the essential tasks of information design. Such escapes grow more difficult as ties of data to our familiar three-space world weaken (with more abstract measures) and as the number of dimensions increases (with more complex data.)

Visually representing the density, complexity, and dimensionality of a learning environment within a limited *n*-dimensional space requires compromise; some elements of a designed intervention need to be privileged in their representation, yet technologies must allow access to representations of all the critical variables and reveal the logic of their interrelations. Tufte's writings (1990, 1997) discuss effects and challenges of several such techniques for "enriching the density of data displays": *micro/macro renderings*, in which exquisite detail leads to both focused micro-readings of individual elements of the design and cumulates into larger coherent structures; using *layering and separation* to reduce noise and distraction and create relative strata amongst related variables; using *small multiples* for comparisons; using *color* to encode abstract information; and *narratives of time and space* that account for the temporal and spatial relations among and among elements in a system.

Tufte's ideas and those of information visualization researchers such as Card (2008), Spence (2001), and Ware (2008) inform a rationale that can be consistently applied across different educational environments for the visual display of instructional workflows, and that takes into account the affordances of the tools used to create the representations—e.g., HTML documents can be hierarchically "layered" using hyperlinks or encoded using cascading style sheets.

A Visual Workflow System for DBR: What Elements are Needed?

What elements (or variables) should be described and included in a "standardized" system of workflow visualization for designed educational interventions? Some probable ones include, as examples: students, instructors, small groups, readings, video, worked examples, discourse, assessment, rubrics, presentation, and analysis. There are many possibilities, and their interrelationships within different designs are complex and multidimensional. Fortunately two sources in the DBR and workflow literatures provide starting points, enabling us to explore these questions systematically. Bielaczyc's (2006) Social Infrastructure Framework highlights four dimensions that researchers need to consider as they design learning environments: cultural beliefs; practices; socio-techno-spatial relations; and interaction with the outside world. The Workflow Management Coalition (Hollingsworth, 1995) identifies five key perspectives—*what*, *when*, by *whom*, using *what data* and *what tools*—that need to be included in a valid workflow expression. These perspectives seem to have significant overlap and are well aligned with other important theoretical frameworks frequently employed in the learning sciences, such as Activity Theory (Engeström, 1999; Kaptelinen & Nardi, 2009; Kuuti, 1996).

Beginning with these frameworks, we conducted research leading to a unique system of visual display to support (a) cross-site sharing, with researchers and teachers, of adaptable instructional interventions invented at various sites, and (b) DBR by allowing researchers to visually depict designed instructional interventions and their assessment output at varying levels of detail, which facilitates data organization, data sharing, and achievement of experimental control. The design of this system itself followed a DBR paradigm. Our primary research questions were: (a) Can we invent a standard workflow-based methodology that can detect and document differences in designed interventions, solve problems of control and efficiency in DBR, and inform theory-based design changes that improve student outcomes in the context of a particular online course that serves as a case study? (b) Can we develop a sound argument that the methods developed for this case study are more widely applicable to the work in environments beyond?

Context of the Study and Data Sources

The context for this study was a special hybrid section of Human Abilities and Learning (HAL Online), an innovative experimental section of an educational psychology course taught regularly at the University of Wisconsin–Madison. The study was conducted in two iterations of the course, spring 2010 and fall 2010, within a 4-week unit on children's thinking that focused on mathematical development. This reusable unit includes four 1-week online sessions and one face-to-face class meeting. The activities that students engage in online include: (a) completing assigned readings and exploring topic-related web resources, (b) viewing videos of children's problem solving, (c) participating in a small group discussion to compare video cases and analyze teaching, learning, or curricula, argue different positions and use course ideas to support arguments, and (d) taking an essay quiz and completing a reflective blog at the end of a unit. In the face-to-face meeting students worked collaboratively in small groups to inductively solve mathematics problems using Unifix Cubes, then presented and discussed their solutions and experiences in terms of the course material. The mathematical understandings acquired in these sessions deepened and supported further online collaborative analysis of videos.

Steps of the investigation:

1. Mining data from course modules and activity logs of online interactions, and from video and interview data collected during the face-to-face meeting, for the purpose of creating initial macro-workflow expressions representing the instructional unit.
2. Interviewing project researchers and teachers from multiple institutions to obtain reactions to initial workflow expressions and the proposed elements used to create them.
3. Generating a pallet of reusable workflow icons from which workflow expressions could be generated, taking into consideration feedback from project members.
4. Iteratively refining the workflow visualization system based on case studies from discussions with project researchers, project managers, teachers, and software analysts and developers given tasks requiring them to use workflow elements to create workflows (Hackbarth, 2011).

The resulting methodological tool represented a synthesis of ideas about social learning environments and their representation (Angelillo, Rogoff, & Chavajay, 2007; Ash, 2007; Barron, 2007; Bielaczyc, 2006) from Learning Sciences literature, the Information Control Nets workflow modeling language (Rembert, 2006) with theoretical grounding in data mining (Fayyad, Piatetsky-Shapiro, & Smyth, 1996; van der Aalst, Weijters, & Maruster, 2004), workflow management (Hollingsworth, 1995; Jablonski & Bussler, 1996), and information visualization (Card, 2008; Spence, 2001; Tufte, 1990, 1997; Ware, 2008) . The major features of this tool are described below and can be experienced dynamically at our website: http://vmc.wceruw.org/workflow/workflow.html

Features of the WVS

We designed icons to build the workflow visualizations and provide visual cues about tasks, information inputs, data outputs (e.g., student learning outcomes), and other lesson elements such as descriptions of the workspace and learning assessments. The various icons can be seen at different levels of Figure 2. Lesson (II) and Lesson Component (III) levels have task icons—they are circular and contain visual cues about the nature of the task and the participation structures (note: each workflow comes with a legend of icon descriptions). Level III, an expansion of the small group activity at Level II, illustrates two individual student tasks—recalling prior knowledge and viewing a video—and a small group discussion. Information visualization principles involving *color* and *shape* are utilized to distinguish input (blue, square, arrow-in) and output (red, square, arrow-out) icons, which serve as hyperlinks that, when clicked on or hovered over reveal more information about a resource, or data visualizations. Finally, hexagon-shaped lesson element icons can be seen at Levels II and III; these include such things as description of the workspace (the small icon at the far-left at Level II), lesson goals, assessments, and task instructions (Level III). Lesson assessment icons are expandable to show another set of trapezoid-shaped icons for formative assessments used for a lesson, scoring rubrics, and summative student performance data. Although not shown in Figure 2, clicking on the Unit Assessment icon at Level I will also provide links to unit-level assessments and student performance data.

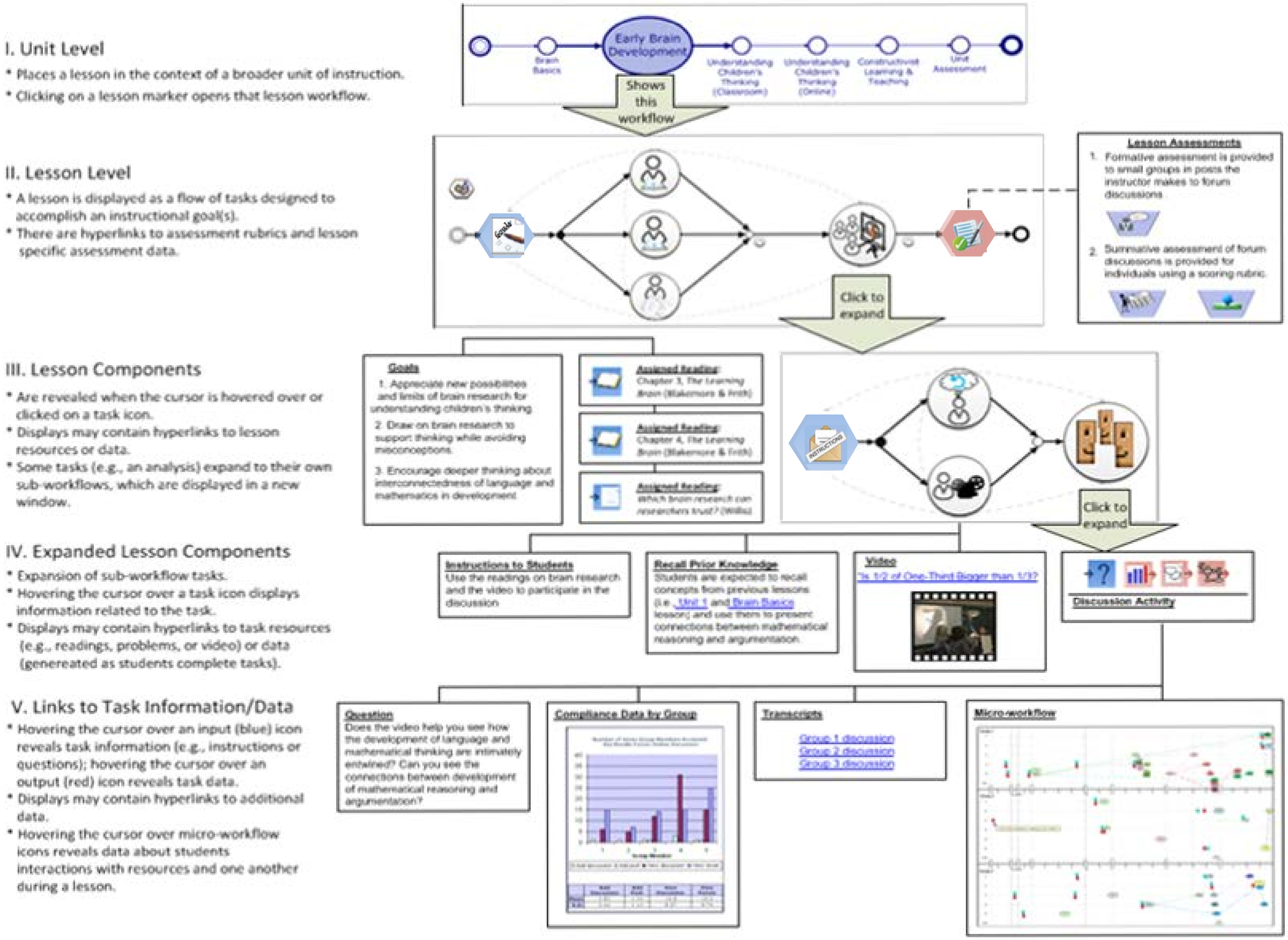
Figure 2 shows the hierarchical and networked organization of a multi-level workflow expression. A dynamic version, which initially displays only the first two levels and opens other levels based on how the user moves the cursor or clicks the mouse, can be accessed at http://vmc.wceruw.org/workflow/ebd-workflow.html. Figure 2 illustrates the depth of information that a workflow representation contains. The *unit* workflow (Level I) places a lesson within the context of a unit and serves as a navigation tool; clicking on a lesson's icon opens that lesson's workflow. The centerpiece of the representation is the *lesson*, or *macro-workflow* (Level II). Task icons are arranged in the order in which they are designed (or recommended) to be accomplished. Dashed lines in the workflow indicate that, while the tasks are given to the learner in a specified order, the learner might start from another point in the lesson, or revisit tasks.

As a user moves the cursor over each task icon, a data repository (i.e., a rectangular box that may hold text only, text and input/output icon(s), or graphical data) opens. The display may include hyperlinks to actual resources used in the lesson or data generated by students doing a task. If moving the cursor over a task icon does not trigger a box to open, then clicking on the icon will open a *sub-workflow* in a new window (right-hand side of Level III). A sub-workflow organizes and displays information about that collection of tasks and functions in a way similar to a macro-workflow; sub-workflow tasks may produce multiple outputs. In Figure 2, the discussion task shows links to compliance data (how and how often a student interacts in the discussion), a transcript, and an analysis of group interaction (a *micro-workflow*).

Functions of the WVS. Primary functions of a workflow representation are to organize the information and (as they become available) research analyses based on learning outcomes data associated with an intervention, and to support archiving, retrieving, and ethical (with respect to student privacy) sharing of design history, outcome data, and analytics associated with DBR. We anticipate that a researcher or educator will have one of two potentially overlapping reasons for viewing and interacting with the representation. One involves *reuse*, possibly after some type of a modification, in which a lesson is borrowed by someone with similar goals or taught iteratively by the designer. A workflow visualization preserves the details of a lesson and assessed learning outcomes, thereby making it available for sharing, reflection, or adaptation. Second, a system's users may be doing *research*, in which case the workflow representation preserves all data in an organized fashion. The visual nature of the representation allows researchers to (a) quickly trace the relationships of different elements of an instructional design, which affords comparison and control across iterations, and (b) potentially see patterns that lead to useful conjectures and suggest avenues for further analyses.

In sum, building on theories from the learning sciences and other related literatures regarding what features of learning environments are important to model, our proof-of-concept prototype served to demonstrate how a Moodle-based system for online course management might simultaneously serve as the basis for a cyberinfrastructure to support DBR researchers in conducting iterative, theory-based online course development, and in facilitating their data collection, archiving, sharing, and mining across projects of various sizes and types. We believe the concept is sufficiently flexible such that, with appropriate enhancements, it could support researchers using varied analytic approaches and conducting research in varied environments.

Figure 2. **An exploded view of the multiple levels of information and data included in a workflow visualization**



Moving Ahead

Next Steps

Can the complex richness of DBR be organized and tamed to enable more systematic, insightful, efficient, community-based inquiry? We propose to address this question by organizing a research community around a project to design, build, and test a prototype cyberinfrastructure for supporting DBR for educational improvement. The cyberinfrastructure we envision will promote systematic collection, archiving, sharing, and collaborative analysis of data from many DBR studies. We envision a standardized yet flexible web-based system that will help researchers document and archive the development and implementation history of designed educational interventions, including their contexts, rationale, iterations, and outcomes across a wide range of projects.

Our next step is to assemble a team and embark on a 3-year NSF-supported collaborative design project that will synthesize recent work in DBR methodology (e.g., Bielaczyc, 2013) with relevant work in areas such as information visualization, machine learning and analysis, learning analytics, and online data mining to create a system with the following kinds of functionalities, although this is not a final or complete description:

- document and share learning-environment designs, including inputs such as activity structures, contextual information, curricular and assessment materials, learning technologies, theoretical design rationales, hypotheses, and outcomes of design experiments;
- provide a standardized web-based resource that will support researchers in designing instructional studies and ethically capturing, organizing and archiving large quantities of data from disparate sources (e.g., instructional materials, assessment, video data) that will be generated when implementing multiple design iterations;
- provide the ability to capture and document design changes, both deliberate design iterations made by researchers or those that occur as products of "on-the-fly" instructional decisions or unforeseen circumstances;
- present real-time, multi-level visualizations that will allow large datasets to be exhibited, shared, traversed, explored, and viewed at different grain sizes and levels of detail to facilitate archiving, sharing, and collaborative data analysis; and,
- provide some level of automatic analysis of data and data mining to facilitate and speed the analytic process and promote the pursuit of some agreed-upon research questions of central importance to the field with data mined from across projects.

Imagine the Future

Data mining. The vision for data mining and instructional analytics within a collective DBR cyberinfrastructure can be contrasted with less theoretical approaches such as those associated with MOOCS and other large courses supported by online management systems. These current approaches generally assume that massive amounts of data produced by large-scale innovations can be processed with machine-learning algorithms to discern patterns that may represent important discoveries about how people learn. However, neither convenient datasets no matter how large, nor intelligent algorithms no matter how sophisticated, will likely yield fruitful results if they are barren with respect to current learning-science knowledge and theory. DBR takes a theory-guided perspective that involves design of learning environments to collect planned datasets that can be analyzed to address what researchers believe are scientifically important questions. That a standardized, community-built cyberinfrastructure can support systematic, theory-based collective mining of data across DBR projects represents a novel and possibly important approach to instructional analytics.

Virtual experimentation within DBR cyberinfrastructure. This concept is intriguing because it suggests an alternative to randomized control trials (RCT) as a possible end game for successful innovations. RCT's require that massive amounts of time and resources be invested in perfecting, scaling, and testing what amounts to single cases of educational innovation. Within this strategy, the complex, interacting environmental factors that influence teaching and learning in context are controlled through a combination of sophisticated statistical, sampling, and experimental procedures that require very large sample sizes and the assembling of massive cooperating teams. The sheer size of such projects requires that measures of success depend heavily on large-scale standardized accountability systems that may not be sensitive to critical learning outcomes deemed important for theory-driven research. Such projects generally require aggregating complex educational features into "intervention packages" that can be implemented, studied and compared across school districts. The requirement for treatment fidelity and control is at odds with the DBR notion of adapting interventions to meet the needs and increase their effectiveness within the implementation contexts in which they are studied.

Contrast the value and cost of such efforts with the possibility of mining an already existing and continuously growing bank of quality-controlled DBR data, designed to increase the likelihood of containing what a qualified research community needs to address its collective questions, to compare, for example, key features of successful versus less successful implementation stories in schools with selected characteristics.

Concluding Comment

The project we propose might develop our model further by building a workflow visualization system that interfaces with an existing course-management system such as Moodle or Sakai and that automatically constructs workflow diagrams of lessons and displays (on request) data collected as learners engage in online learning activities. The system may serve as an interface to provide the same functionality for other learning environments, including hybrid or face-to-face settings where different information or communication technologies might be used or adapted to upload data about interventions and learner-produced artifacts that are created outside the course-management system.

Or, this collaborative design project engaging an entire design-research community might take new and unanticipated directions.

References Cited

Ailamaki, A., Ioannidis, Y. E., & Livny, M. (July, 1998). Scientific workflow management by database management. *Proceedings from the 10th international conference on scientific and statistical database management*, Capri, Italy.

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research? *Educational Researcher, 41*(1), 16–25.

Angelillo, C., Rogoff, B., & Chavajay, P. (2007). Examining shared endeavors by abstracting video coding schemes with fidelity to cases. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 189–206). Mahwah, NJ: Lawrence Erlbaum Associates.

Ash, D. (2007). Using video data to capture discontinuous science meaning making in non-school settings. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 207–226). Mahwah, NJ: Lawrence Erlbaum Associates.

Barab, S. A., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences, 13*, 1–14.

Barron, B. (2007). Video as a tool to advance understanding of learning and development in peer, family and other informal learning contexts. In R. Goldman, R. Pea, B. Barron, & S. Derry (Eds.), *Video research in the learning sciences* (pp. 159–188). Mahwah, NJ: Lawrence Erlbaum Associates.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences*, *12*, 307–359.

Bielaczyc, K. (2006). Designing social infrastructure: Critical issues in creating learning environments with technology. *The Journal of the Learning Sciences, 15*(3), 301–329.

Bielaczyc, K. (2013). Informing design research: Learning from teachers' designs of social infrastructure. *The Journal of the Learning Sciences, 22*(2), 258–311.

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

Card, S. (2008). Information visualization. In A. Sears & J. A. Jacko (Eds.), *The human-computer interaction handbook: Fundamentals, evolving technologies and emerging applications* (2nd Ed.) (pp. 509–544). New York, NY: Lawrence Erlbaum Associates.

Cardoso, J., Bostrom, R. P., & Sheth, A. (2004). Workflow management systems vs. ERP systems: Differences, commonalities, and applications. *Information Technology and Management*, *5*(3-4), 319–338.

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

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the Learning Sciences, 13*(1), 15–42.

Dede, C. (2004). If design-based research is the answer, what is the question? A commentary on Collins, Joseph, & Bielaczyc; diSessa & Cobb; and Fishman, Marx, Blumenthal, Krajcik,

& Soloway in the JLS special issue on design-based research, *Journal of the Learning Sciences*, *12*(1), 105–114.

De Roure, D., Goble, C., & Stevens, R. (2009) The design and realization of the myExperiment virtual research environment for social sharing of workflows. *Future Generation Computer Systems*, *25*(5), 561–567.

Derry, S. J., Pea, R. D., Engle, R. A., Erickson, F., Goldman, R., Hall, R., … Sherin, B. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences*, *19*(1), 3–53.

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen, & R.-L. Punamaki (Eds.), *Perspectives on activity theory* (pp. 19–38). New York, NY: Cambridge University Press.

Engle, R. A., Conant, F. R., & Greeno, J. G. (2007). Progressive refinement of hypotheses in video supported research. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video research in the learning sciences* (pp. 239–254). Mahwah, NJ: Erlbaum.

Fadel, C., & Lemke, C. (2006). Technology in schools: What the research says. Culver City, CA: Metiri Group-Commissioned by Cisco Systems. Retrieved June 3, 2013, from www.cisco.com/web/strategy/docs/education/**TechnologyinSchools**Report.pdf

Fayyad, U., Piatetsky-Shapiro, G., & Smyth, P. (1996). From data mining to knowledge discovery in databases. *AI Magazine*, 37–54.

Georgakopoulos, D., Hornick, M., & Sheth, A. (1995). An overview of workflow management: From process modeling to workflow automation infrastructure. *Distributed and Parallel Databases*, *3*, 119–153.

Gil, Y., Deelman, E., Ellisman, M., Fahringer, T., Fox, G., Gannon, D., … Myers, J. (2007). Examining the challenges of scientific workflows. *Computer*, *40*(12), 24–32.

Grinstein, G. G., & Ward, M. O. (1994). Introduction to data visualization. In U. Fayyad, G. G. Grinstein, & A. Wierse (Eds.), *Information visualization in data mining and knowledge discovery* (pp. 21–46). San Francisco, CA: Morgan Kaufman Publishers.

Hackbarth, A. J. (2011). Workflow visualization: Design, development and evaluation of a system to support design-based research and sharing of learning interventions (unpublished doctoral dissertation).

Hackbarth, A. J., Derry, S. J., Eagan, B. R., & Gressick, J. (June-July, 2010) *Adapting workflow technology to design-based research: Development of a method for organizing the "messiness" of research in technology-rich online learning environments*. Paper presented at the 9th International Conference of the Learning Sciences, Chicago, IL.

Hollingsworth, D. (1995). Workflow management coalition: The workflow reference model. *The workflow management coalition specification*. Hampshire, UK: Workflow Management Coalition.

Jablonski, S., & Bussler, C. (1996). *Workflow management: Modeling concepts, architecture, and implementation.* London, UK: International Thompson Computer Press.

Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K. (2011). *The 2011 horizon report*. Austin, TX: The New Media Consortium.

Kaptelinen, V., & Nardi, B. (2009) *Acting with technology: Activity theory and interaction design*. Cambridge, MA: The MIT Press http://portal.acm.org/citation.cfm?id=1803882.

Kuuti, K. (1996). Activity theory as a potential framework for human-computer interaction. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction.* Cambridge, MA: MIT Press.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, *11*, 65–99.

Ludäscher, B., Altintas, I., Berkley, C., Higgins, D., Jaeger, E., Jones, E.A., Tao, J., & Zao, Y. (2005). Scientific workflow management and the Kepler system. *Concurrency and Computation: Practice and Experience*, *18*(10), 1039–1065.

Mentzas, G., Halaris, C., & Kavadias, S. (2001). Modelling business processes with workflow systems: An evaluation of alternative approaches. *International Journal of Information Management*, *21*, 123–135.

Merriam, S. B. (1988). *Case study research in education: A qualitative approach*. San Francisco, CA: Jossey-Bass.

Muir, M. (2007). Research summary: Technology and learning. Retrieved from http://www.amle.org/Research/ResearchSummaries/TechnologyandStudentLearning/tabid/275/Default.aspx

Noeth, R. J., & Volkov, B. B. (2004) Evaluating the effectiveness of technology in our schools. Iowa City, IA: ACT Policy Report. Retrieved from http://www.act.org/research/policymakers/pdf/school_tech.pdf

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher*, *40*(7), 331–337.

Rembert, A. J. (March, 2006). Comprehensive workflow mining. *ACM Southeast Regional Conference: Proceedings of the 44th Annual Southeast Regional Conference*, Melbourne, FL.

Schacter, J. (1999). *The impact of education technology on student achievement: What the most current research has to say*. Santa Monica, CA: Milken Exchange for Education Technology, Milken Family Foundation. Retrieved from www.eric.ed.gov/ERICWebPortal/recordDetail?accno=ED430537

Spence, R. (2001). *Information visualization*. Harlow, UK: Addison-Wesley.

Tegarden, D. P. (1999). Business information visualization. *Communications of the Association for Information Systems*, *1*(4), 1–37.

The Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5–8.

Tufte, E. R. (1990). *Envisioning information*. Cheshire, CT: Graphics Press.

Tufte, E. R. (1997). *Visual explanations: Images and quantities, evidence and narrative*. Cheshire, CT: Graphics Press.

van der Aalst, W. M. P., Weijters, A. J. M. M., & Maruster, L. (2004). Discovering process models from event logs. *Transactions on Knowledge and Data Engineering*, *16*(9), 1128–1142.

Ware, C. (2008). *Visual thinking for design*. Burlington, MA: Morgan Kaufmann.

Wiggins, G., & McTighe, J. (2005). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.