Workflow Visualization: Design, Development and Evaluation of a System to Support Design-Based Research and Sharing of Learning Interventions

By

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Abstract

This is a two phase design study of a methodology and tool called the *Workflow Visualization System* (WVS). It is used to produce intermediate representations that: help researchers *do design studies* of learning interventions of dynamic, multi-dimensional classroom and online environments; and facilitate sharing of interventions for adaptation and reuse by educators and researchers. In an initial "messing about" cycle I tested workflow mining and data visualization concepts (Rembert, 2006: Tufte, 1991) by creating "digital napkin sketches" of a workflow representation design and vetting them with my research team. In a second cycle I refined the system and built web-based, multi-layered, interactive prototype visualizations of five lessons in an undergraduate online course offered at the University of Wisconsin – Madison. The prototypes were used during the subsequent evaluation phase of my study. I used *case study* methodology (Merriam, 1988; Stake, 2003) and Yin's (2003) idea of *explanation building* to analyze data collected from two distinct but related groups of users; my research team members, and senior researchers, designers, educators, and research project managers from Rutgers University. Results of analyses of meetings and interviews indicate that: potential users could interpret the meanings of icons and workflows and felt they could create workflows of their own designed learning interventions; the tool would impact their research by providing large-grained views of data to identify areas for finer-grained analysis; open new areas of research by providing more organized contextual detail, and facilitate rapid comparison of interventions across different contexts. There was agreement that there needs to be a tool developed to easily create visualizations, automate data collection, and annotate elements in the *intended* and *actual* workflows during and after implementation. These, and other suggestions regarding user interface preferences, will be incorporated into the WVS in the next design cycle.

I. Introduction

Design-based research is a relatively new research paradigm that addresses the challenge of systematic design and study of instructional strategies and tools (Barab & Squire, 2004) grounded in the "blooming, buzzing confusion" of classroom learning environments (Brown, 1992) or similar authentic contexts whose complexity can make "systematic study" a daunting prospect. It is important when doing design-based research (DBR) to identify the critical factors of an *intended* instructional intervention and how those factors fit together (Collins, Joseph, & Bielaczyc, 2004). Not all factors that influence the implementation of a design experiment can be controlled (p. 19) – e.g., the availability of videos on a website, or students' lack of prerequisite knowledge or experience. In order to evaluate the *actual* implementation of an instructional design one needs to analyze each case in terms of its key elements (i.e., resources, workspaces, and personnel's roles) and the factors that influence their implementation, or lack thereof. Some elements will be implemented more or less as the designers intended, some will be changed to fit the circumstances, and some will not be implemented at all (p. 34). A profile of how each of the critical elements were (or were not) implemented and how well the elements worked together toward the designer's goals is needed. Furthermore, because each element is part of a systemic whole it is impossible to change one aspect of the system without creating perturbations in others (Brown, 1992). These perturbations, as well as their effects on predicted outcomes, need to be identified and accounted for in the 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, because major changes mark the borders that differentiate one phase of an implementation from the next (Collins, 1992). The outcome is a detailed design history that characterizes the design elements that are in place in each phase and the reasons for the transitions from one phase to the next. The design history reflects design changes and whether they have any causal impact on measured student outcomes, which lead to theory building and allows research audiences to evaluate the credibility of design decisions and the quality of lessons learned from the research (Barab & Squires, 2004).

However, in the service of documenting and studying design, researchers usually end up collecting large amounts of multivariate data during an intervention - e.g., video, student produced artifacts, plans, interview data, or activity logs from online interactions - often more data than they have time or resources to analyze (Barron, 2007; Brown, 1992; Collins, Joseph, & Bielaczyc, 2004). In addition the relations of elements of the design may become lost in the mountains of data without an organizational framework to preserve them. To ensure that design researchers maximize their use of the targeted, collected data to develop rich representations of critical variables and their interactions in a learning environment, Merriam (1988) argued for analytical procedures that organize and document data in an easily accessible format that facilitates more efficient deeper analyses.

Intermediate Representations

Barron (2007, p. 178) and Derry et al. (2010) discuss the emergence and value of *intermediate representations* as a response to this long-standing challenge. While the concept of an intermediate representation carries different meanings in different domains, they focused on field research emphasizing collection of video data. They argue that intermediate representations are important for initially organizing complex datasets to facilitate identifying what to analyze and for understanding patterns within and across the data. It is in this sense that I use the concept. Barron identifies several examples of intermediate representations that are either created during data collection or are derived from an initial *macro*-analysis of video records. These representations utilize textual and visual features and 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 (i.e., family) informal learning experience and highlight significant events for deeper analysis (for example, see Ash, 2007); *descriptive diagrams* of interactions which illustrate participants' (i.e., family) relations to one another and resources in an informal learning situation (for example, see Angellino, Rogoff, & Chavaj, 2007): and *conversation maps* that show the flow of discourse in a learning situation and help to identify patterns of differential responding to problem-solving proposals (Barron, 2003).

In these examples macro-level organizational structures are imposed on the data and help the research teams develop a sense of the corpus and facilitate the selection of episodes for further detailed analysis (Barron, 2007, p. 179). Further analysis may lead to refined hypotheses (Engle, Conant, & Greeno, 2007), the discovery of new unanticipated phenomena that generate new hypotheses, or design changes that lead to a new implementation cycle.

Macro-level intermediate representations may also be the appropriate level for sharing the details of a successful designed intervention with practitioners. This would satisfy a core requirement of DBR that the development of sharable, adaptable learning interventions that are of practical use to practitioners is intertwined with the goal of developing theories or "proto-theories" of learning (Collins, 1992, The Design-Based Research Group, 2003). Applied to the context of a classroom or online learning environment, standardized representations of pedagogical processes may emerge in a manner similar to the way various approaches of "scripting" group interactions (e.g., elaboration, explanation, argumentation, modeling cognition, and question asking) have evolved from the work of researchers in collaborative learning, (King, 2007; Kobbe et al., 2007; Kollar, Fischer, & Hesse, 2006). Standardized representations may also help facilitate design by showing at a high level the key elements of a design and their relationships. This would allow researchers to hypothesize about the effect on learning outcomes of changing the order of elements or the content of a particular element.

A Design Study

My dissertation research is a design study of a methodology and tool to produce intermediate representations that help researchers *do design studies* of learning interventions applied to complex, dynamic, multi-dimensional classroom and online environments. The methodology and tool are also intended to facilitate sharing of interventions for adaptation and reuse by educators, or for collaboration among researchers. The first phase of the study consisted of two cycles of design and development of a theoretically-grounded methodology and web-based tool that I call the Workflow Visualization System (WVS). In the first "messing about" cycle of design work, which resulted in WVS 1.0, I drew ideas and tools from fields that include the learning sciences, social psychology, business, applied science, computer science, and information visualization to help develop a set of orienting questions to guide my design work. During my review of literature I tested workflow mining and data visualization concepts by creating "digital napkin sketches" of a workflow representation design and vetting them with my research team members. In the second design and development cycle (leading to WVS 2.0) I used feedback on WVS 1.0 to develop a refined system that consisted of a library of generalized icons to represent elements of a learning intervention, rules for organizing them into a "workflow" representation, and web-based techniques for hiding and revealing layers of information based on user actions. I then used WVS 2.0 to build web-based, multi-layered, interactive prototype visualizations of a unit of five lessons in a Human Abilities and Learning online course (HAL Online) offered in the Educational Psychology Department at the University of Wisconsin – Madison. These WVS-produced prototypes were input for the subsequent evaluation phase of my study in which I analyzed data collected from two distinct but related groups of users. One group comprised the HAL Online (henceforth HAL-O) research team members (including myself) at the University of Wisconsin - Madison who were invited to make use of WVS 2.0 in their research. I also evaluated WVS 2.0 based on data collected from a representative sample of potential users – senior researchers, designers, educators, and research project managers from Rutgers University -- who are my team's research partners in a broader NSF-funded project. These data were based on recordings and notes from interactions with these users during my presentations that explained the system and the prototype HAL-O visualizations to them; from workflow building tasks I created to let me observe users engage with the system; and from interviews with the potential users.

The broader NSF-funded project is the Video Mosaic Collaborative (VMC), which is developing an interactive digital environment, Video Mosaic (http://videomosaic.org/), to support video-based teacher professional development and related research. Offered through Rutgers University Libraries, Video Mosaic makes available on the World Wide Web indexed, annotated video cases on students' mathematical reasoning spanning two decades of developmental research from the Robert B. Davis Institute for Learning. My study informs the development of tools and a methodology intended to support sharing and analysis of the designed video-based learning interventions that will make use of the videos and will be archived in the Video Mosaic.

This dissertation primarily reports evaluation results from the second phase of my design research, with recommendations and examples of how the system will evolve in the next design cycle, which will involve fully programming the system. Because the next cycle will require resources beyond my current capacity, I have submitted an NSF grant application to support the work and am currently engaged in collaboration with instructional designers and programmers from the University of Wisconsin – Madison's Division of Information Technology (DoIT) on a pilot study to partially implement the next design iteration for the Moodle course development environment.

Orienting Research Questions. There were three major questions that guided the design and development of the WVS in phase 1.

1. *What kind of intermediate representation can account for the volume and diversity of data generated in a complex, dynamic, multi-dimensional designed learning environment, and support rigorous analysis and comprehensive sharing of the design?*

2. With respect to the potential of information visualizations to serve as intermediate representations, *what visual metaphor will fit the structure of a complex, dynamic, multi-dimensional designed learning environment*?

3. *What elements need to be included in a workflow visualization of a designed educational intervention, and what are their relationships*?

In the next chapter I address these questions and synthesize ideas from a number of domains, including information visualization, workflow representation, workflow mining, activity theory, and the social infrastructure of learning environments. The result is a conceptual framework for the WVS.

Evaluation of the WVS. At the core of the WVS methodology are a few conditional rules and a lexicon of symbols and icons. The combination is used to create web-based visualizations that organize the elements of designed learning interventions into generalized macro-workflows of *intended* lesson designs. Each prototype visualization that I created for the study also contained layers of data about the *actual* implementation of an intervention that could be accessed by users (researchers or educators), and that might reveal relations and patterns and places that warrant deeper analysis or description (if the objective is sharing an intervention for adapted reuse). In this sense the workflows are intermediate representations that reveal the *intended design* of an intervention and its *actual implementation*. The information and data revealed in these intermediate representations facilitate additional, more focused intermediate representations and deeper analyses or "thicker" descriptions of the intervention (Geertz, 1973.)

The overarching question posed in phase 2, the evaluation phase of my work, was: *how does a workflow visualization serve as an intermediate representation that supports design-based research and sharing of designed interventions*? In addition to the question posed earlier about what elements of an intervention need to be included in a workflow visualization, more specific questions that guided the evaluation phase of the study included:

1. How does the WVS balance representation of the context of an intervention (needed to support analysis and sharing of the intervention) with the abstractness of workflows (needed to support generalization and reuse)? How is the context of a designed intervention represented in a workflow visualization? How is abstraction (i.e., generalized pedagogical structures) represented?
2. Can workflow visualizations capture and show differences in interventions that may lead to theory-based explanations of differences in outcomes?

3. How would the workflow visualization approach developed in this study have to be modified so that researchers and instructors would use it to create intermediate representations of interventions that take place in other contexts and learning environments, e.g., entirely face-to-face environments or short-duration professional development seminars such as occur in the larger research project?

I derived hypothetical answers to these questions from a synthesis of the literature across several domains that influenced design decisions I made and served as a starting point in the evaluation of the system during which I posed these questions in various ways as I interacted with representative potential users. Settings for the evaluation sessions included HAL-O research team meetings and meetings with Rutgers VMC project members. The Rutgers meetings were organized into five case studies that represented reactions and viewpoints of senior project principal investigators (PIs), teacher educators, research project managers, a former systems analyst, and software developers.

Summary of the Study.

I designed, developed and evaluated the efficacy of a web-based workflow visualization system to: address the challenges of representing the large number and range of elements and their intertwined relationships in a design experiment; assist researchers taking a design-based research approach in achieving control in the manipulation of variables, which occurs between implementation phases of the design process; and provide sharable models of interventions that are adaptable to local contexts.

In the following chapters I will elaborate on the research literature that supported my study, describe the methods used, report the results of two design iterations, and discuss implications for the third phase of my design work.

II. Synthesis of a Conceptual Framework from Numerous Domain Literatures

I begin by elaborating, using examples, on the idea of intermediate representation as it has been used to organize data and reveal interesting relations and patterns in educational research. Because the WVS includes finer-grained *micro-workflows* of individual students and small groups, I also discuss examples of finer-grained visual representations of learner interactions that have features similar to those I incorporated into the WVS. I then use the three main questions that guided the design and development of the WVS to frame a discussion of the ideas that underlie the logic of my study, which includes theoretical frameworks related to information visualization, workflow representation, workflow mining, activity theory, and the social infrastructure of learning environments.

Intermediate Representations

As noted previously, I adopted a definition of intermediate representation from Barron (2007, p. 178) and Derry et al. (2010) that was derived from field research of educational environments that involved the organization of raw video data to facilitate iterative, more focused analyses. Here I share several examples that show the importance of intermediate representations in educational research. Some are macro-level that help researchers organize and "see" patterns in datasets at a higher level, and some are micro-level that provide finer-grain formalisms of sampled data. These examples illustrate the wide range of styles and levels of granularity of intermediate representations. These were all used not to analyze designed learning environments, per se, but to help each researcher see interesting points or patterns in their data that might promote generalization or be further analyzed.

Table-based flowchart. Ash's (2007) answer to the problem of dealing with the complexity of a learning environment, and the consequent overwhelming quantities of data collected from such environments, evolved from her research to accurately represent and analyze the actions and meaning making dialogues created by social groups (i.e., families) during their visits to informal science learning settings (i.e., the zoo). To answer the recurrent question of how her research group could generalize from very specific microgenetically-detailed, episode-based analyses, Ash developed a methodology that includes using several levels of analysis in an interlinked way that she describes as "moving between levels of macro to micro analyses." The challenge her method addresses is to be able to maintain a general overview of events while simultaneously isolating detailed and representative events. The first level, called the *Flow Chart* (Figure 1), is large-grained and holistic; it provides a chronological overview of one entire visit to the zoo (40-60 minutes) as well as pre and post interviews (15-20 minutes each).

Family J, Mother, Father, daughter (Eva, 10), son (8), son (Ricardo, 5) Interpreter (HQ) & Researcher (EB) June 14, 2001. FC Prep EB			
Time	Exhibit	Overview	Content
0-30:00	Pre interview with Splash Zone (SZ) cards[1].	Long, rich, interview. Mom talks most. She uses the SZ cards to start conversation. Family has been in USA 10 years.	Frequent museum goers, Museums are fun, better than flea market; all members have favorite animals.
30:00-33:00	Family walks into museum	Eva is the lead, the family follows, all walk to the SZ. Eva is bilingual.	Eva points to the whales on the ceiling, very animated
34:50	Whole family is looking at otters	Some talk about otter behavior Dad/kids lead, MBA is crowded	At the otter tank briefly—Is otter asleep–how would you know?
37:00	Looking at video of whales in the hallways.	Family separates; Mom listens attentively & questions Eva.	Whale is Eva's favorite animal, because they communicate, Blue whale has smaller flippers.
39:02	EB/Eva talk about whales	Eva the lead, walking to the SZ EB listens,	Eva explains her classroom work studying Orca, killer whales
41:00	First coral tank	Looking closely, not in a hurry Dad the lead, asks lots of question, What are those plants in there? Mom leads next with more questions, they are animals?	Conversation about coral —Is it plants or animal; what do they eat? —they eat other animals and that live in layers.

***Figure 1*. Sample of a table-based flowchart.**

An intermediate level called the *Significant Event* consists of one segment (i.e., row) of the Flow Chart that can be analyzed in greater detail, emphasizing dialogue, content, and the kinds of tools the group uses to make sense of the science and connect it to their own prior understanding. Another level that drills deeper into a selected significant event supports microgenetic studies that examine details of dialogue, gesture, gaze, and actions over time. While the Flow Chart concept is a fairly theory-independent descriptive level of analysis, the details and selection at the other two levels are dependent on the research questions chosen and by the theoretical framework in which the researcher works.

Descriptive diagrams. Angelillo, Rogoff, & Chavajay (2007) described the evolution of *bird's eye view diagrams* (see Figure 2) that portrayed the extent and type of mutual engagement in problem solving scenarios between Guatemalan Mayan mothers with varying levels of schooling and three school-age children as they constructed a 3-D totem jigsaw puzzle. Initially diagrams were an informal way that researchers communicated to one another about the roles of participants *vis a vis* group activity. But a number of useful conventions emerged for depicting who was involved with whom and how they were involved, such as acting together, observing, directing others, and playing supporting roles, and the diagrams became useful for analysis and representation of findings.

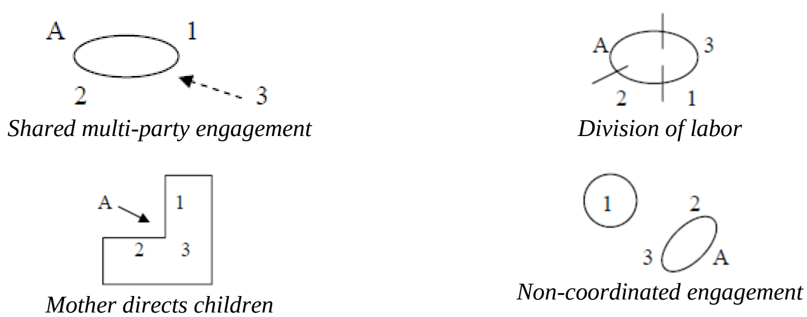


***Figure 2*. Examples of descriptive diagrams.**

By using one diagram to depict the predominant form of engagement per one minute segment as viewed on videotape, researchers ended up with several pages of small but detailed diagrams for each family's group session (about 30 minutes). Pages were laid out on a long counter to first simplify the categories and then to examine whether any patterns were evident by mother's schooling experience (0-2 grades, 6-9 grades, 12+ grades). The clarity of the diagrams allowed researchers to use 'eyeball analysis' to understand complex patterns in the data in a matter of only a few hours of examination of the sheets, which were later graphed in more abstracted ways and eventually analyzed statistically.

Conversation maps. Once transcripts of an interaction are created, the spatial layout of turns can be designed to make phenomena easier to see. Barron (2007, 2003) describes her own use of a *conversation map* in a study of small group interactions during a problem solving activity. In her study, the turns of each speaker were entered into a unique column and linked by arrows labeled according to an emerging and dynamic coding scheme. The maps hung on her office walls and, while not used to share outcomes of her research, were instrumental in helping her see patterns of differential responding to problem solving proposals that were key to later quantitative coding and qualitative analysis.

Micro-level Visualizations for Finer-Grain Analyses. When a researcher wants to investigate the interrelations of a large number of variables that describe an environment or the activity of participants, both individually and as they interact with one another, she or he may employ a music score representation to organize the data. Information is arranged on a collection of horizontal lines (or rows) with each line marked with data that is related, for example, to a person, event, or resource. The Chronologically-Ordered Representation of Discourse and Tool-Related Activity (CORDTRA) is an example of a lined music score representation used to organize information on a large number of dimensions (Figure 3). Hmelo-Silver, Chernobilsky, & Jordan (2008) argue that CORDTRA diagrams facilitate discourse analysis by allowing for holistic visualization of data while at the same time enabling fine grain coding and representation of different aspects (i.e., discourse, tools, or structures) of computer-based problem solving environments. In that sense, it would accomplish the same analytical function as Ash's multi-level model of representation. In Figure 3 the CORDTRA diagram shows multiple processes plotted in parallel, allowing a researcher to juxtapose a variety of codes to understand an activity system. Keyword Maps in the video analysis tool Transana™ (http://www.transana.org/about/Tour/Keywords1.htm) and the Annotation Board in the video analysis tool ANVIL© (http://www.anvil-software.de/) provide similar functionality.

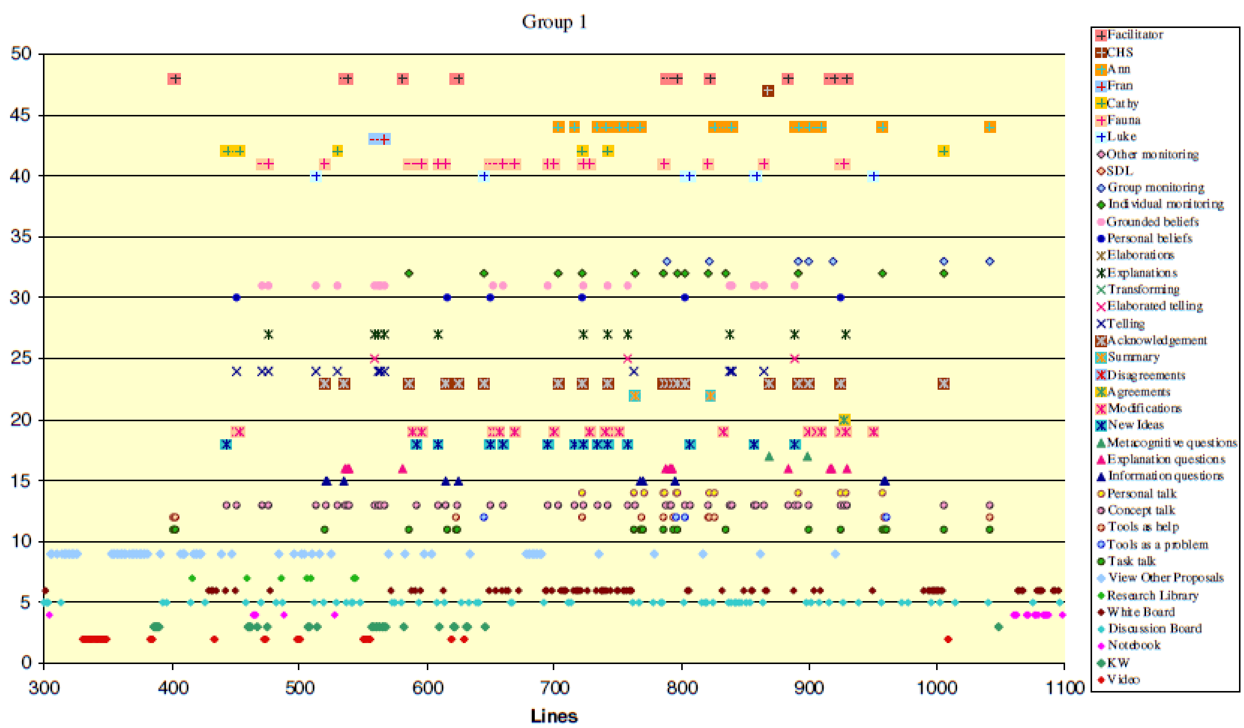


***Figure 3.* An example of a CORDTRA diagram. Data categories are plotted according to what line of a transcript of video of an activity they occur.**

Wortham (2008) developed an Activity Theory (AT)-based model for representing interactions of a small group engaged in a science lab (Figure 4) where he organized the actions of individual members of as rows in a table. Within each row he identified mediators and tensions that prompted actions by individual students and used parenthetical reference numbers to show the flow of discourse between group members. The representation shares some similarities with Ash's (2007) Flow Chart; for example, both account for distinct actions across an activity (Ash in a column; Wortham in rows) and both summarize individual contributions and group interactions within cells in the table. Like Ash's, the model is not particularly *visual*; a viewer needs to study the text of the cells to understand what is occurring and if a represented pattern of discourse is meaningful.

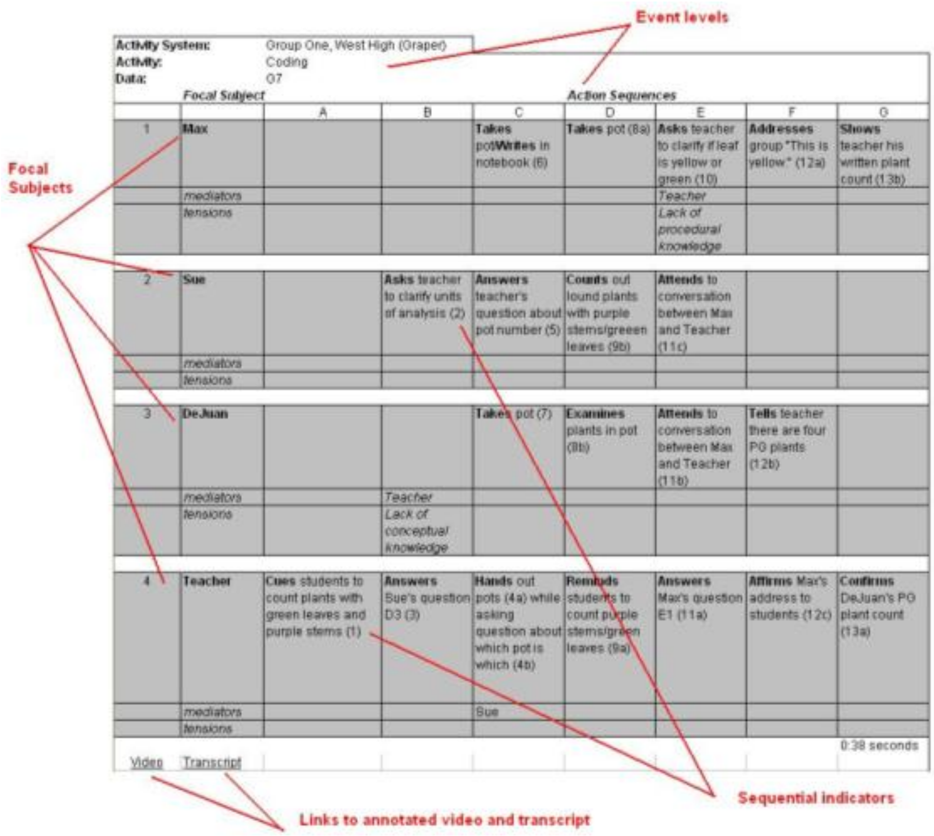
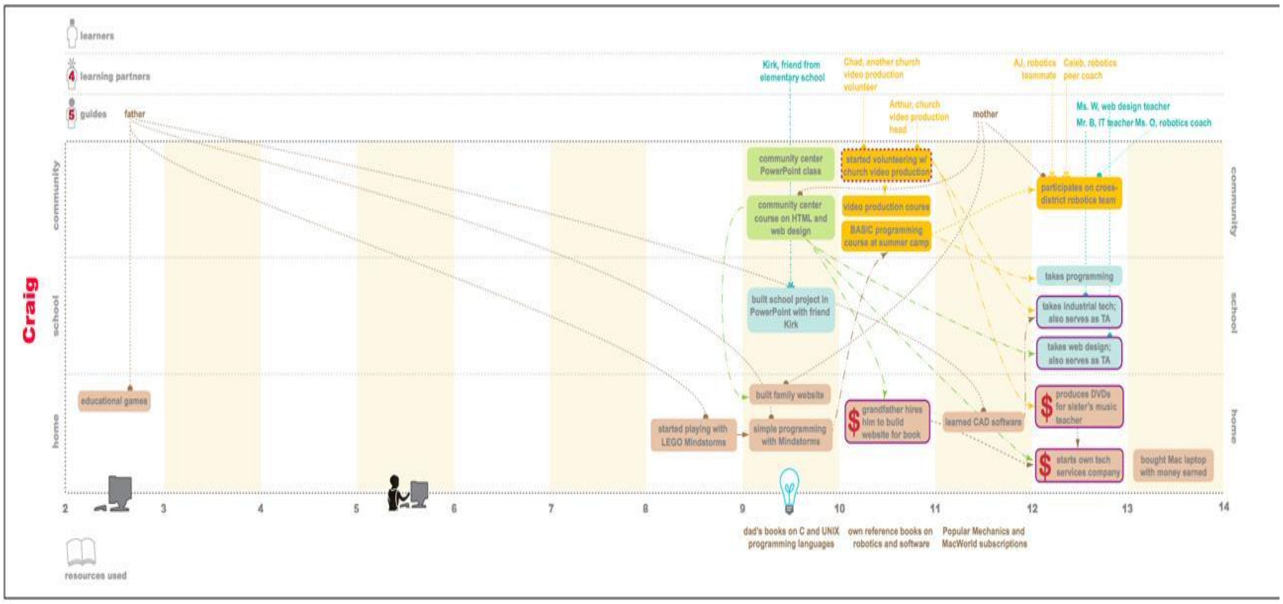
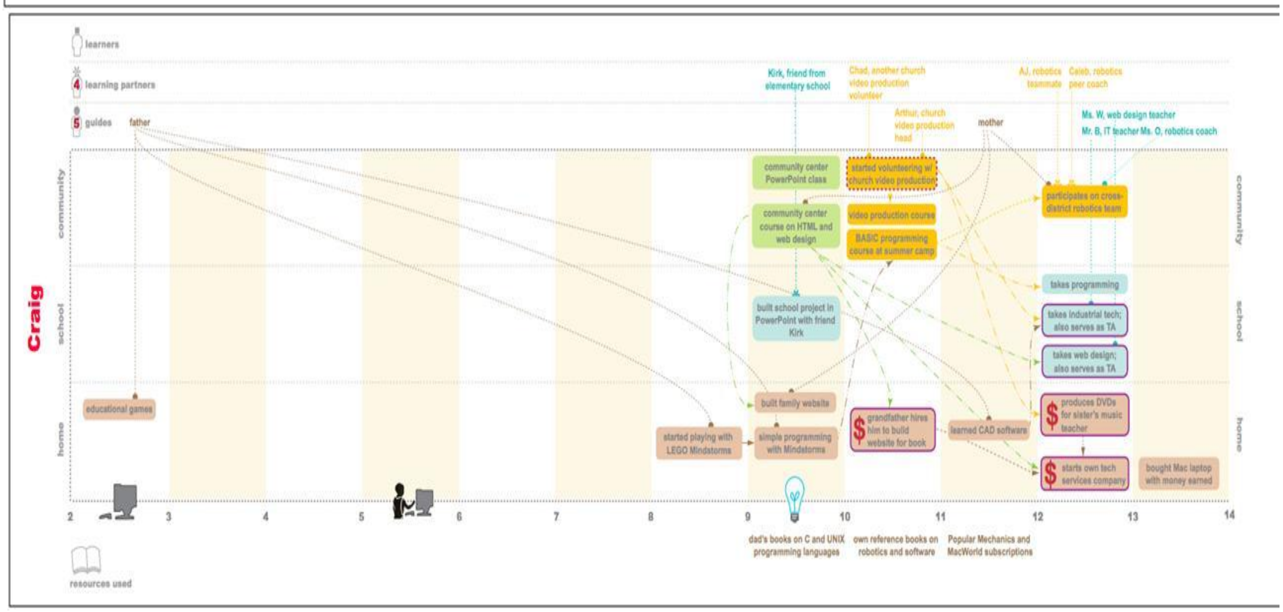


***Figure 4.* Wortham's (2008) coded activity record.**

Another interesting representation developed and used by researchers in the Learning in Informal and Formal Environments Center (LIFE) supports multi-level analyses of children's learning ecologies (Eberbach & Bernstein, 2009). The researchers collected data through interviews with parents, mentors, and the middle school students themselves and observations at home and in community centers. They mapped activities and learning resources in timeline representations (Figure 5) and saw patterns of learning activity that linked formal settings with informal learning opportunities (i.e., camps, clubs, churches, or online communities).





Key

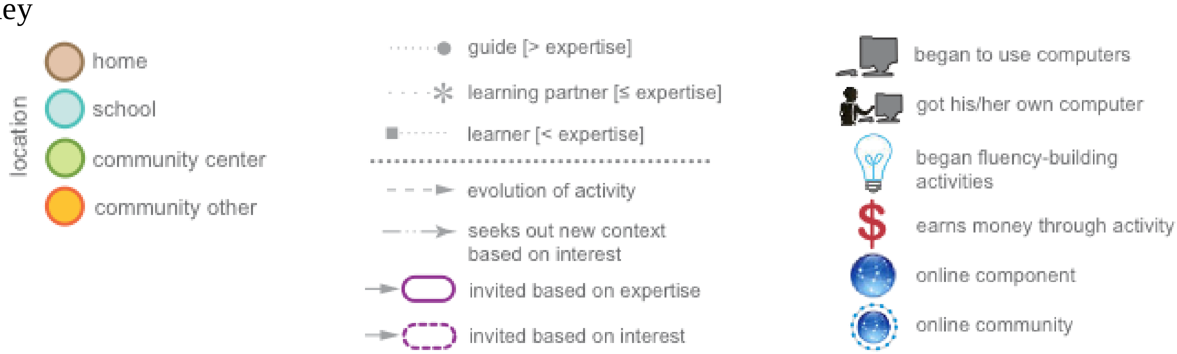


***Figure 5*. The LIFE Center visual timeline representation of a child's learning ecology.**

The LIFE Center representations utilize several principles of visual design (Ware, 2008) - symbols, colors, and shapes (lines and terminal points) along with descriptive labels to enhance the visual aspects of the representation.

Discussion. The intermediate representations overviewed above are a few examples of researchers' informal efforts to gain some control over large amounts of data and organize it in ways that facilitate systematic archiving, sharing, study and insight. They each include some characteristics of useful information visualizations (that I will elaborate in the next section: (a) data represented on multiple levels with a higher level representation aiding the exploration of mid- and micro-level representations; (b) standardized visual elements that achieve clarity through abstraction to create a continuous description of group interaction from discrete "snapshots" of data, and; (c) explicitly mapping the flow of activity or data. However, none of the methods includes all of these characteristics. Moreover, the generality of these systems is unclear; therefore the scope of their application may be limited. The visualization system that I have developed incorporates all these characteristics into one tool that fills a need for an efficient standardized activity mapping tool. Instructional designers, researchers and educators can use the WVS to share interventions and study learning in a broad range of learning environments.

The examples that include micro-level visualizations illustrate types of tools that researchers are developing to try and represent the complexity and dimensionality of learning environments. Rather than producing intermediate representations that are primarily organizational and descriptive, these formalisms (Chi, 1997) produce more complete accounts of one or more events according to analytical categories chosen by the researcher. These micro-level representations are more context-bound and point to or constitute data related to specific questions. The micro-workflows produced by the WVS share some features of these types of representations but attempt to address the problem of how to generally represent learners' interactions with resources and each other in a standard way that can, with some adaptations, be used across varied contexts.

Information Visualization

My search for and consequent development of the WVS was initially guided by the question; *what kind of intermediate representation can account for the volume and diversity of data generated in a complex, dynamic, multi-dimensional designed learning environment, and support rigorous analysis and comprehensive sharing of the design?*

This question is not unique to the challenge of design-based researchers and educators. Writing about decision-makers in the world of business, David Tegarden (1999) observed that they suffer from information overload while at the same time underutilizing large amounts of data. He cited as an example the New York Stock Exchange where, in the first four months of 1995, an average of 333 *million* response-sensitive transactions were processed *each day*. From the community of applied science Robert Spence (2001) identifies data management challenges such as charting world-wide tide phases from thousands of measurements, or analyzing millions of bits of satellite data to learn about earth resources. They and others (Card, 2008; Grinstein & Ward, 2002) report on how information visualization technologies have helped solve these dilemmas.

The widely accepted definition of information visualization is "*the use of computer-supported, interactive, visual representations of abstract data in order to amplify cognition*" (Card, 2008). Visualizations harness the perceptual capabilities of the human visual system and allow 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. Larkin and Simon (1987) argued that diagrams can be superior to written representations because they can group related information together and use location to aid in information search. Diagrams also aid in making perceptual inferences and 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 malleable medium (Card, 2008). Computers increase the cognitive capability of the human visual system because they allow for interactive, multi-dimensional graphic representations that organize and thereby reduce the search for information. This enhances the detection of patterns, enables perceptual inference operations, and supports efficient computational processes by distributing them between brain and computer (Spence, 2001).

It is useful to understand how the human visual system integrates with the brain to perform cognitive functions. Colin Ware (2008) writes that it is unnecessary to keep a complete copy of the world in our brains; “It is much more efficient to have rapid access to the actual world for the task at hand – to see only what we attend to and attend to only what we need.” (p. 2.) That we sample the visual world on a kind of need-to-know basis leads to a different model of perception that Ware calls *visual thinking* and defines as “a series of acts of attention that drive eye movement and tune our pattern finding circuits” (p. 3). Attention is multi-faceted; eye movements, which occur in tenths of seconds, are driven by the analysis of an image on the retina by pattern-finding mechanisms. These mechanisms pull out the pattern most likely to help with whatever we are doing. At a cognitive level we allocate scarce working memory resources to briefly retain a focal attention only to those pieces of information most likely to be helpful. This conception of attention as *visual queries* – a series of searches for particular patterns – allows us to think about visual representation of information from the perspective of what design features would help facilitate productive visual searches.

If we make sense of the world through just-in-time visual queries, then the goal of information design must be to produce displays so that queries are processed both rapidly and correctly for every important cognitive task the display is intended to support. One issue, then, is what can be easily seen; what does it take to make a graphic symbol that can be found rapidly? How can something be highlighted? A second issue for designers is the emerging concern for developing *intrinsic quality measures* (Chen, 2005) that will answer key questions such as to what extent does an information visualization design represent the underlying data faithfully and efficiently? To what extent does it preserve intrinsic properties of the underlying phenomena? These are by no means easy questions; the nature of the data and complexity of the corresponding visualization influences the search for such measures.

With regard to symbol or pattern detection, the simple features that guide the search process and determine what we can see easily are *color*, *orientation*, *size*, *motion*, and *stereoscopic depth* (Ware, 2008). Research has shown that there is a strong correspondence between these "pop-out" effects and early visual processing mechanisms. Contrasting these features across different channels in the visual system makes complex designs more easily searchable.

The ultimate design question is whether salient features of geometric or structural patterns convey the intended message to the viewer (Chen, 2010). The attachment of meaningful geometric or visual encoding is much more arbitrary when viewing a visualization of an abstract topic (i.e., analysis of a journal article) than when viewing a scientific visualization of, for example, a thunderstorm. Research on how humans visually process the world as we solve problems has provided a great deal of insight on how to design visualizations that help viewers solve particular problems related to the information on display (Ware, 2008). Many of these insights have been incorporated into Edward Tufte's (1990, 1997) principles for enriching the density of data displays. These principles are summarized in Table 1.

***Table 1*. Tufte's principles for information design.**

Principle	**Characterized by:**
Micro/macro readings	Representation of information entails detailed renderings of individual pieces that are arranged into a coherent whole. Focusing on a detailed individual piece (micro-reading) provides information about that piece; zooming out to view the whole (macro-reading) affords the viewer to see relations between the parts and (potential) patterns and/or points of interest in their interconnectedness.
Layering and separation	Visual stratification of various aspects of the data. In print media this is accomplished by means of distinctions in shape, value (light to dark), orientation (relation of parts to one another), size, weight, and especially color. In a computer workspace it is accomplished with tools such as hyperlinks that open new windows, smart tooltips (that, for example, display interactive graphics and text when the users mouses over an image or highlighted text), and suites of filtering tools (e.g., zooming, panning, or search tools).
Small multiples	Consistency of the core design of an object or image. Changing the appearance across multiple instantiations by altering one feature (associated with a variable of interest) facilitates visual comparison.
Color	Fundamental uses; to label (color as noun), to measure (color as quantity), to represent or imitate reality (color as representation), to draw attention (color as contrast), and to enliven or decorate (color as beauty).
Narratives of space and	Relationships between two or more objects across two or

time	more dimensions. These are often depicted using other principles, e.g., layering and separating and small multiples.

The Selection of a Visual Metaphor

A key problem for information visualization designers involves identifying *visual metaphors* for representing information and understanding the analysis tasks they support (Gershon & Page, 2001). Designers of visualizations tend to capitalize on metaphors that can give users a sense of intuitiveness and/or familiarity. From a user's point of view such a visualization is either easy to understand or easy to learn through interaction. Shneiderman (cited in Chen, 2010) summarizes the essential elements of interacting with graphically presented information: overview first; zoom and filter; and then details on demand. The all important function of an overview is to depict interrelationships among units of information. Information space metaphors are popular because they invite navigational operations such as zoom, pan, or rotate that allow users to understand information intuitively or understand it quickly through interactions with the visualization. In addition, a graphic design that has visual structures at several scales can aid in the search process; large scale structure provides a means for finding important mid- and small-scale information (Ware, 2008). Thus, a second important question regarding the potential of information visualizations to serve as intermediate representations is *what visual metaphor would fit the structure of a complex, dynamic, multi-dimensional designed learning environment*?

The use of workflow representation as a metaphor and tool for evaluating and sharing interventions in the Video Mosaic was embedded in the proposal for the Cyber-Enabled Design Research to Enhance Teachers' Critical Thinking. However, it was not fully articulated in the proposal how ideas about workflow from the distinct domains of business and applied science would be synthesized and operationalized in an educational environment. In this dissertation I used literature from business and applied science to describe the evolution of workflows in both fields and identify characteristics and principles that make workflow representation a suitable and valid visual metaphor for designed educational interventions. There are also unique challenges that educational environments pose for workflow representation that I identified, which are discussed in a following section. Because it is well known and widely used in the field of learning sciences, I also examined Activity Theory (Engström, 1999; Kuutti, 1995) as an alternative source for a visual metaphor.

Workflow in business and applied science environments. The concept of workflow emerged from the notion of *process* in manufacturing and business systems (Mentzas, Halaris, and Kavadias, 2001). According to Georgakopoulos, Hornick, and Sheth, (1995) *business processes* are typically developed to fulfill a business contract or to satisfy a specific customer need and are implemented as information and/or material processes. 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 intervention; instruction can be generally described as a series of processes – including material and information processes – intended to collectively satisfy instructional objectives (i.e. a contract) and satisfy a learners' (i.e. customers') needs.

The Workflow Management Coalition (WMC) 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”.

Linking multiple basic units together creates a workflow representation, a static image that visually describes the flow of information and tasks and may be used to automate and control all or part of the flow of the system (Georgakopoulos, Hornick, and Sheth, 1995). Workflow representations vary in terms of detail depending on their purpose; high level conceptual workflow representations are often used to give general explanations of a system’s function, whereas a significantly more detailed workflow representation is required to analyze processes at an application level (Ludäscher et al., 2005). Multi-layered workflow representations are often used to describe or analyze a single system. When computer-based technology is applied in order to separate and hide layers of information and make it available when a user interacts with the representation in certain ways (e.g., mouse-over or clicking), a *workflow visualization* is born (Spence, 2001).

In the scientific community, greater value is placed on access to specialized tools or necessary registers of data that allow scientists to conduct sophisticated analysis or simulations from their desktop computers:

> “…[the] user defines the process needed for problem solution as a flow of activities, each capable of solving a part of the problem...Resources that perform these activities are not necessarily located in the user’s vicinity rather they are geographically distributed. This may enable the use of unique resources such as expensive measurement instruments or powerful computer systems.” (Brandic et al., 2006).

A key feature that facilitates the ability of scientists’ to conveniently put together and run their own scientific workflows is the notion of reuse (De Roure, Goble, and Stevens, 2008). Scientific workflow expressions 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. This idea of reuse 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 instantiations. 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 here to teachers or designers who introduce new inputs (e.g., data or concepts) while reusing a pedagogical process (e.g., a worked example) from lesson to lesson, and to sharing adaptable interventions.

Literature from business and applied science suggest that an important kind of technology is embedded within the workings of a system that organizes tasks and tools in a particular sequence, manages the flow of data to and from the tools, executes the tasks in such a way as to accomplish an overall objective, and controls the system's output. A similar organization of information, tools, people and tasks underlies the processes *and products* of design-based research. For example, a high level workflow for DBR is summarized in Figure 6.

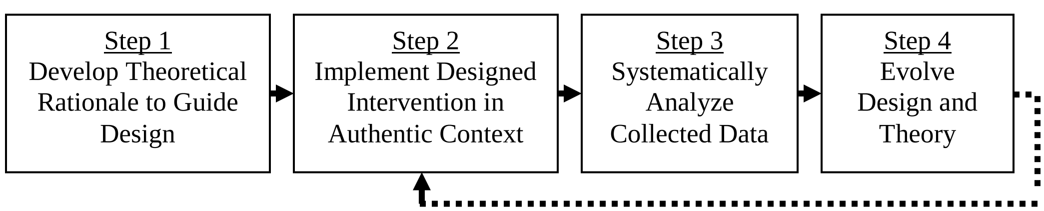


***Figure 6.* Steps in a designed-based research workflow.**

The implementation of a designed intervention in step 2 can be unpacked and represented with workflow representations created at varied levels of detail. For example, at levels that I call the *macro-workflow*[1] levels, workflow representations facilitate identification and control of the many variables that intersect during an educational intervention and sharing of adaptable educational interventions with other educators who can modify the general framework represented by the workflow representation to accommodate local contexts. More detailed views at *micro-workflow*[2] levels provide finer-grained representations derived from data that both constitute and facilitate deeper analysis (step 3) in the iterative process of DBR.

Workflow technology is often documented before or as a system is created, *but it can also be discovered, e.g., in the modules and activity logs for a computer-supported system,* and exploited to help describe the processes of a system or to learn about how people use a system's tools, resources, and processes as they interact within it. Visualizations that represent the "before and after" aspects of a system can provide powerful information about the system; for example, how an intervention was intended to be implemented and how it was actually experienced by students and teachers.

Challenges for workflow representation of educational environments. When adapting workflow technology to educational settings it is important to think about how to represent control flow (emphasized in business) to show the sequence of processes in an intervention (Mentzas, Halaris, & Kavadias, 2001), and data flow (emphasized in scientific work) that allows researchers to see how information is accessed and acted upon throughout the intervention (Gil et al., 2007). Educational environments are like both business and scientific environments; at the same time they are unique.

As Collins, Joseph, and Bielaczyc (2004) and Brown (1992) point out, first and foremost is the variability and unpredictability of learners and teachers, who come to an intervention with

[1] Loosely related to *macro-scripts* (Dillenbourg & Hong, 2008), macro-workflows describe the environments in which desired interactions are designed to occur in terms of activities, resources, and tools.
[2] Like *micro-scripts* (Dillenbourg & Hong, 2008), micro-workflows emphasize individuals' activities.

varied degrees of relevant prior knowledge (Bransford, Brown, & Cocking, 1999). This results in changes to the processes in an intervention; for example, prerequisite knowledge sometimes needs to be activated (or taught), sometimes additional or alternative conceptual or physical tools need to be introduced to a process, or sometimes groups need to be reconfigured for various reasons. Variability in designs and/or implementation can also be caused by factors that are out of the designers hands – e.g., a specialized room is not available or a person is not available when needed and as a consequence a sequence of lessons must be altered. This variability and unpredictability suggests that while educational interventions may be initially represented as "intended workflows,"[3] they cannot be preprogrammed in the way that many business-oriented workflows are (e.g., loan applications or trip reservations). This further suggests that important functions of an educational workflow visualization include capturing and representing: (a) The intended but adaptable aspects of interventions that can be shared and reused across diverse educational and research settings; (b) The actual workflow of an intervention expressed in terms of the processes students and teacher(s) actually engaged in and if, or how often, they used lesson resources and concepts to engage with one another to accomplish lesson goals; and (c) detailed data flow within interventions, which supports scientific analysis associated with design-based research.

In the first two cases macro-workflow representations can be used to represent the designed intervention under study. Macro-workflow expressions can be equated with educational *macro-scripts* – general pedagogical models that aim to create learning situations in which productive interactions and outcomes will hopefully occur (Dillenbourgh & Hong, 2008; Dillenbourg & Tchounikine, 2007). If the purpose is analysis of an activity, particularly group

[3] Dillenbourg (2004, p. 3) compares "intended scripts", i.e., the instructions and/or structures that were designed to achieve a particular kind of interaction, to "actual scripts", i.e., the task or group interactions that students do actually engage in. "Intended *workflows*" act in the same way.

collaborative activities, more detailed *micro-workflow* representations (equated with "micro-scripts") can be used.

Activity Theory: An Alternative Not Taken. *Activity Theory (AT)* (Engström, 1999; Kaptelinin & Nardi, 2006; Kuutti, 1995; Leont'ev, 1979; Wertsch, 1981) is a conceptual framework that is frequently used to describe individual and collective problem-solving actions in more or less complex environments. It employs a multi-tiered triangle as a visual metaphor to show connections and relationships of various elements of the framework (see Figure 7).

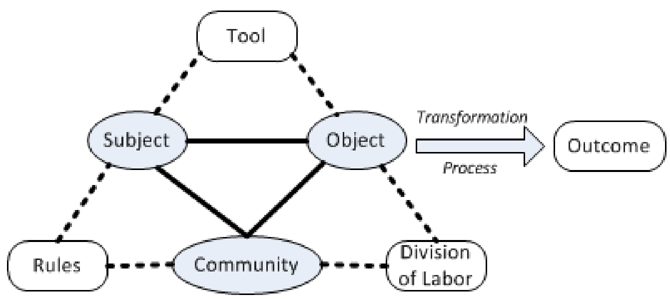


***Figure 7.* Activity Theory: Basic structure of "activity".**

Because activity theory is widely adopted in the learning sciences and supplies a visual metaphor, I considered the possibilities and problems of using activity theory to support data visualization of educational interventions. According to Aleksei Leont'ev (1979), the ultimate cause behind human activity is *needs*. When a need becomes coupled with an *object* an activity emerges. From that point on the object becomes a *motive*, and the need not only stimulates, but also directs the *subject* toward an *outcome*. An object can be a material thing, but also less tangible things like a plan or even a common idea, as long as it can be shared, manipulated, and transformed by the participants of the activity. Activity is "a system of processes oriented toward the motive" (Kaptelinin & Nardi, 2006), where the meaning of any individual component of the system is determined by its role in attaining the motive. In terms of that terminology and structure, activity theory is compatible with the concepts of workflow for representing educational interventions.

Other elements that contribute to the framework of AT depicted in Figure 7 are also descriptive of important elements of a learning intervention. For example, a third component in the model – *community* (i.e., students, teacher, parents, etc.) – creates additional relationships (*rules* and *division of labor*) that mediate activity in the learning environment. While all elements in a systemic whole have a relationship to all other elements, key relationships in this model include:

- Subject and object, mediated by *tools* (in an educational environment - readings, videos, simulations, etc.).
- Subject and community, mediated by *rules* – (i.e., how to act in school, classrooms, groups, etc.).
- Object and community, mediated by *division of labor*.

Activity theory also provides a hierarchical structure and terminology to account for the sequencing of activity (Kuutti, 1995; Leont'ev, 1979; Wertsch, 1981) – much like a workflow is sequenced into tasks. Activities are longer-term formations and usually their objects cannot be transformed into outcomes all at once. The transformation occurs through shorter-term processes that consist of *actions* that are directed by goals and mediated by both tools and a division of labor (i.e. an activity is divided into a chain of actions.)

This segmenting and sequencing of activity into actions makes visual representation using the triangle metaphor depicted in Figure 7 a complicated proposition. For example, consider a lesson sequence with the motivation of developing knowledge about problem solving that consists of reading a related book chapter, solving a math problem, viewing a video of a student explaining her solution to the same problem, and making a post to a discussion forum assessing the solution or explanation presented in the video. Applying the simplest subject-tool-object-goal model of activity to each action results in the four models of lesson actions shown in Figure 8.

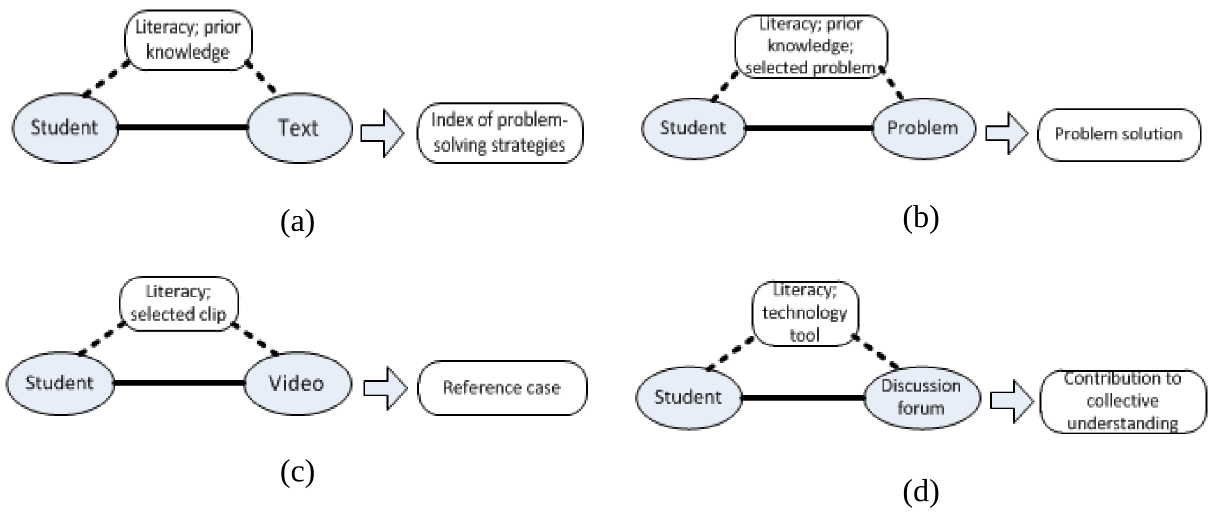


***Figure 8.* Basic Activity Theory models of lesson actions: (a) read a textbook, (b) solve a problem, (c) watch a video, and (d) post to a discussion forum.**

In a model of the over-arching activity, in which these four representations of actions would have to be integrated, at least two major decisions have to be made: 1) when to expand the basic triangle metaphor to include the *community* component and *rules* and *division of labor* mediating elements (as in Figure 7) – should it be done at each action-level or at the activity-level and 2) where to place these action-level models? Should they be located as objects that motivate or direct activity, or are they tools that mediate activity? Or are they simply representations of the division of labor – the way activity is parsed into shorter-term processes? Regardless of their position, are these action-level visualizations nested, or networked, or displayed in some other configuration? And what determines if an action is or is not an operation?

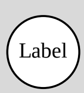
It didn't take long for me to realize that using the AT triangle to represent a learning intervention would be difficult to do and would result in overly complex visualizations. While Activity Theory provides a useful framework for conceptualizing the relations inherent in processes people engage in at various levels while acting in the world (Nardi, 1996), it is a difficult visual metaphor for organizing information to facilitate analysis of a learning intervention. Therefore, I retained workflow representation as the visual metaphor to create visualizations of interventions.

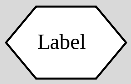
Comprehensive Workflow Mining

Comprehensive workflow mining - "the rediscovery of an explicit control flow model given a workflow event log" (Rembert, 2006) - describes the actual work of building a workflow visualization. During workflow mining, information and data are collected from lesson modules, activity logs, or as student-produced artifacts and converted into a meaningful arrangement of symbols that is the surface layer of a structured repository of information about a particular implementation of a designed intervention. Much of the literature on workflow modeling focuses on the use of Petri-Nets to automate and analyze business processes (for example, Meena, Saha, Mondal, & Prabhakar, 2005; Tick, 2005; van der Aalst, Desel, & Oberweis, 2000), a highly structured, mathematics-based methodology that describes processes in terms of weighted nodal relationships between places and transitions. The focus on control flow of this method of workflow modeling is too narrow to describe the relevant dimensions of a learning environment. However, the Collaboration Technology Research Group (CTRG) at the University of Colorado – Boulder has developed a workflow modeling language called Information Control Nets (ICN) that is graphical and intuitive and broadens the scope of workflow mining to include a wider range of perspectives than Petri Nets (Rembert, 2006). The primary perspectives included in this modeling methodology include: (a) the **functional** perspective – *what* tasks or activity must occur; the **control flow** perspective – *when* tasks are done; (b) the **informational** perspective – *which* data is processed and the *data flow* of the process; (c) the **resource** or **organizational** perspective – *who* or *what* performs a task; and (d) the **operational** or **application** perspective – *how* a task gets done (Jablonski & Bussler, 1996; Rembert, 2006; Tick, 2007; van der Aalst & van Hee, 2004). These perspectives are derived from the Workflow Management Coalition's Basic Process Definition Meta-Model – the organization's definition of what belongs in the specification of a workflow (Hollingsworth, 1995).

In general, relevant data are mined from the event logs of the management system that supports the execution of a workflow. However in educational environments data can be "mined" from other sources, such as field video and interview data. The ICN workflow modeling language has a mathematical and graphical representation; for this dissertation study I used only the graphical elements of representation, shown and described in Table 2:

***Table 2*. Graphical elements of the ICN workflow modeling language.**

	*Tasks* are represented by labeled circles. A task is an atomic unit of work carried out by one or more people.
	*Data repositories* are represented by labeled squares. Data repositories have production/consumption relationships with tasks, meaning they provide data that is consumed by a task or collect and hold data produced by a task.
	*Roles*, Which can be comprised of individuals or groups, are represented as labeled rounded rectangles. Roles are often specified in terms of features such as responsibilities, authority, and availability.
	*Participants* are represented as labeled stick figures. An organizational population specifies which participants belong to which role/group, as well as relationships amongst participants.

 	If a task requires a certain *application type*, e.g., “email”, to be completed, then that task might be accomplished by any *application instance* of the type specified, e.g., “Gmail” or “Outlook”. An application type is represented with a labeled hexagon; an application instance is represented as a labeled computer monitor.
	There are four *control tasks*; two branch tasks - parallel and conditional, and two join tasks – synchronization and merge. *Parallel branches* split between two or more concurrent tasks while *conditional* branches mark a choice between two or more tasks. A *synchronization* join indicates that all tasks directly preceding it must be completed before it can start. A *merge* can begin execution when any of the tasks directly preceding it have completed execution. Parallel branches and synchronization joins are marked with an unlabeled dark circle. Conditional branches and merges are marked with an unlabeled open circle.

I found the ICN workflow modeling language and methodology developed by the CTRG to be effective for visually representing the processes of a system in terms of control flow, data flow, participants and their roles, and tools – in short many of the kinds of variables identified by Collins (1992) and Collins, Joseph, & Bielaczyc, (2004) as important to account for in design experiments.

Elements of a Workflow Visualization of an Educational Intervention

A related design question is *what elements need to be included in a workflow visualization of a designed educational intervention, and what are their relationships*?

I have discussed perspectives of the WMC Basic Process Definition as a framework that contribute *structural* elements to the design of a workflow visualization, but what *contextual* elements of a designed educational intervention need to be represented so that the visualization facilitates design-based research and efficient sharing of interventions? In introducing the idea of a design experiment, Collins (1992) stated that a long term goal of studying technology innovations in school was to construct a design theory that would attempt to specify all the variables that affect success or failure of different designs, attempt to specify what values on these variables maximize chances for success, and attempt to identify how different variables interact in creating successful design (p. 19). In the Social Infrastructure Framework (SIF), Katherine Bielaczyc (2006) has identified critical variables synthesized from a number of design experiments and organized into four dimensions, expanded below, that researchers need to keep track of during the design, implementation, analysis, and revision cycles of DBR.

The Social Infrastructure Framework. The SIF evolved from research grounded in those initial goals and represents a synthesis of findings from research on learning communities (Bielaczyc & Collins, 1999) and computer supported collaborative learning environments (Bielaczyc, 2001). The SIF is a conceptual tool for accounting for and examining the social environments and practices, in physical and cyber spaces, associated with designed learning environments (Bielaczyc, 2006). Four dimensions, which are amenable to design and therefore important for comparative study and evolution of learning interventions, are described below.

The cultural beliefs dimension. Cultural beliefs refer to the mindset of the teacher(s) and students that shape the way of life in the classroom. Cultural beliefs are not designed per se but they are cultivated over time, and influence such things as how learning and knowledge are conceptualized, goals (e.g., performance vs. learning), how collaborative/competitive identities of students are shaped, how the identity of the teacher or teachers is understood (in terms of power relations, for example), and how the purpose of technology-based tools is viewed.

The practices dimension. This concerns the ways in which teachers and students engage in activities. Of primary interest is data that can reveal how the activities of the intervention operate as a system in which they mutually influence and reinforce one another with respect to overall objectives of the intervention (Brown & Campione, 1996). Also of interest is how students engage in activities: individually, in groups, or both? Is there a theoretical rationale for how groupings of students are organized or what roles they take on within groups, or how their modes of interaction are supported or constrained (Kollar, Fischer, & Hess, 2006)? A third area of interest is in the role the teacher plays in the classroom, both in terms of activities and tool use. For example, Bielaczyc and Collins (1999) note a contrast between teachers *directing* activities versus *facilitating* student-directed activities (p. 275); the degree to which a teacher balances control with opportunities for exploration and self-directed learning influences students' sense of ownership and autonomy. A related critical aspect of the practice dimension concerns whether specifications for activities, participant structures, and tool use are *fixed* or *principle-based*, which impacts the level of adaptability students have with respect to, for example, how they work in groups or how they use tools. The role of a teacher(s) extends beyond a participant structure. Implementation decisions made by a teacher, often "on-the-fly", impact what activities or tools get privileged as students "mesh" (Derry et al., 2005) multiple concepts in order to achieve learning goals.

The socio-techno-spatial relations dimension. This dimension refers to the organization of physical space and technology-based workspaces and how they support or constrain teacher and student interactions. Consideration of the physical space needs to be related to how it accommodates anticipated activities and groupings, for example; is there adequate space, can furniture be flexibly rearranged, are mechanisms for sharing information (e.g., whiteboard, projectors) readily available, are there adequate sources of power for technology, how many computers (or other technological tools) are available and how they are accessed, what are the expectations for sharing technology-based information and can that be accommodated by the physical resources? The affordances and constraints of the technology-based tools presents another set of issues; how pervasive is the use of technology in the intervention (e.g., very high in an online class and less so in a didactic classroom), how is access provided, how is information treated in the workspace (e.g., private or public, restricted or open, mutable or static), how are students expected to use tools to interact in the workspace, how is the teacher expected to interact with students through the tools, and how are technology-based activities coordinated with off-line activities?

The interaction with the "outside world" dimension. Interaction with the outside world refers to the online and offline ways students are able to interact with people and be influenced by their engagement in events outside their immediate classroom environment. Aspects of interaction to consider include: how is knowledge brought in from "the outside" (e.g., videotape, video-conferencing, the Internet, or invited guest speakers); how is student work extended out to an outside audience (e.g., opportunities for students to actively present or to passively display their work to a community-of-practice or community-at-large in public or online forums); or how are opportunities made available to collaborate with others in/from the outside (e.g., service-based learning projects or "sister schools")? The door usually swings both ways with respect to the outside world; both students and the "outside" they interact with are influenced by the experience, and that can change the environment on the "inside". For example, teachers who engage in a professional development course are often asked to implement practices in their classrooms based on the theories they are studying in the course. The interactions often change not only their classroom environments, but also their collegial interactions in the PD course.

Discussion. As can be seen in the previous section, the SIF makes explicit many critical variables of classroom social structures that need to be specified and/or monitored when designing, implementing, evaluating, and refining technology-rich learning environments. With respect to workflow visualizations, the dimensions of the SIF provide a reference point for a specification of elements of a designed learning intervention.

The major goals of the WVS design project are to design visual icons and organize them into structures from which designers, researchers, and educators can account for or access information about the key variables of the SIF described above and understand, or hypothesize about, how they contribute to a learning intervention. By looking at an icon in a workflow visualization a person should be able to infer with a high degree of accuracy information such as what task is being performed and by whom (i.e., individual, small group, or whole class). By interacting with the icon (i.e., mouse-over or click) a person should get additional specific information such as; the goals of a lesson, how those goals will be assessed, what resources they are expected to use (e.g., chapter or article to read or video to view), how they are expected to use the information or skill acquired from doing a task, what tools they are expected to use, or how they are expected to interact with others (i.e., instructor, other students, or "outsiders"). By "zooming out" to a view where interconnected icons represent a lesson structure a person should be able to infer with a high degree of accuracy the order in which tasks are intended to be completed, how much flexibility students have to complete the lesson, how much of a lesson is individual-based versus small-group versus whole-class, and details about workspaces (e. g., physical versus cyber-based, or lecture versus lab configuration). By viewing representations of a number of lessons in a course over time a person should be able to chart details from the SIF *practice* dimension, such as if an instructor is inclined to direct activities or facilitate student-directed activities, and make inferences about SIF *cultural* dimension variables – for example, how the designer or instructor conceptualizes learning, or how the identities and relationships of instructor and students are operationalized.

III. Method

Design Goals and Process

I employed a modified *design-based research methodology* as defined in the Learning Sciences (Brown, 1992; Collins, 1992; The Design-Based Research Collective, 2003) to evaluate the efficacy of workflow visualizations to serve as intermediate representations that organize data to inform design-based research of educational interventions and facilitate sharing of those interventions. I did not engineer a learning environment, but rather a web-based Workflow Visualization System (WVS) that consists of a library of icons that are representative of educational tasks and resources, and a methodology for combining them into macro-level visual representations of a designed intervention, annotating the representations with data automatically logged by a course management system (i.e., Moodle) as students and the instructor interact with resources and one another in the CMS, and summarizing student (and instructor) interactions with lesson resources and one another in multi-dimensional micro-workflows. The WVS methodology was an adaptation of the ICN workflow modeling language (Rembert, 2006) with theoretical grounding in information visualization (Card, 2008; Tufte, 1990, 1997; Spence, 2001; Ware, 2008), workflow management (Hollingsworth, 1995; Jablonski & Bussler, 1996), and data mining (Fayyad, Piatetsky-Shapiro, & Smyth, 1996; van der Aalst, Weijters, & Maruster, 2004).

The study spanned a design phase and a systematic formative evaluation phase. Results of the evaluation are expressed as recommendations for the next design phase. The design phase consisted of two cycles in which I became familiar with workflow mining and data visualization concepts during a “messing about” cycle where I sketched and vetted with research team members various workflow representations of a HAL Online lesson; and developed an initial theoretically-driven design of a workflow visualization system (WVS 2.0) and implemented it to produce web-based workflow visualizations of a unit of instruction. During this phase of the project I observed and worked with a professor and two graduate student researchers (the HAL-O design team) who were using a design-based research approach to incorporate VMC resources from a combinatorics strand into lessons on children's mathematical reasoning. During their work they attempted to use and commented on my developing visualization designs.

The context for this initial design work was two iterations of the course, Spring 2010 and Fall 2010, which focused on a four-week unit on brain development and children's mathematical thinking. The unit included four one-week online sessions and one face-to-face class meeting of two and one-half hours. The professor for the course had developed well-articulated modules on the Moodle course site that provided much of the data I needed to conceptualize my designs. These included a list of tasks to be completed for each session and links to most of the resources that students used when completing the unit. In each semester the course enrolled 27 students who were organized into groups based primarily on their areas of study. Students' grade levels ranged from sophomore to graduate students. The course was a requirement for education majors and a recommended elective for several other majors; the classes included nutritional science, rehabilitation psychology, communicative disorders, kinesiology, and psychology in addition to teacher education majors. Diverse geographic and socio-economic backgrounds were represented in the enrollment. To support development of the initial workflow visualizations I recovered online data on two groups of education students and one group with majors related to sports and fitness. Random identifiers were used instead of group and student names for all analyses.

The usual activities that students engaged in during an online session included:

- reading a chapter from the course text and/or other assigned readings.
- viewing a video(s).

- participating in a small group discussion in which they discussed, compared cases, analyzed or argued different positions.
- taking a quiz and completing a reflective blog (at the end of a unit only).

In the face-to-face meeting students heard a lecture on social learning, worked in their small groups to solve a mathematical problem using Unifix cubes, presented their solutions, viewed a video of fourth grade students solving the same problem, and discussed the various solutions in terms of general problem solving strategies.

In the evaluation phase I collected and analyzed data from a sample of representative users from the VMC project -- senior PIs, project managers, a project instructor, research assistants, software developers, and a computer systems analyst (See Table 3 for a detailed list) -- for the purpose of determining the efficacy of the workflow visualization system for supporting research and sharing interventions. From the analysis of meeting and interview data I derived recommendations to evolve the design of the WVS in the next design phase.

Tools and Data Sources

In the following sections I will describe the tools used to design and evaluate the WVS. Each section includes separate subsections for tools (or instruments) used and data sources.

Design phase. This was progressive work; first I designed icons to represent lesson elements (e.g., tasks, inputs, and outputs), which involved selecting appropriate shapes, images, sizes, and colors. Next I employed and modified ICN workflow language rules to develop rules for connecting icons into workflow visualizations. I also adopted methods for hiding and displaying information – essentially, I developed hierarchical and network structures for data. Finally, I wrote and edited HTML and CSS (Cascading Style Sheets) code to animate the system in a web browser.

Tools. I employed several graphic and web design tools, including:

- Microsoft Visio: is an advanced diagramming tool with an extensive library of shapes and connectors that I used to: 1) combine shapes and graphics to create cons, 2) to combine icons into workflow representations, and 3) to save Portable Network Graphic (PNG) images of icons and workflows to be used in web-based workflow visualizations.
- GIMP: is an open source image manipulation program similar to Photoshop that I used to chart the dimensions of image hotspots.
- Alleycode: is a free HTML editor that I used to write and test HTML and CSS code.
- jQuery: is a JavaScript library that simplifies HTML event handling: displaying dropdown menus, opening information displays, and organizing information with tabs.
- Highslide JS: is a JavaScript tool that I used to create image galleries.

Data sources. Nearly every icon in a workflow visualization has some form of data associated with it. For example, a reading assignment includes a specific reading; a discussion produces a transcript. The following is a list of data sources:

- Lesson modules: Moodle modules can be organized to include information such as lesson goals, assignments, suggested schedules, and links to resources (Figure 9). From the online modules I extracted data about the intended flow of tasks during the lesson, the resources that support those tasks, links to the resources, and the tools students were to use to process or create information. This information was used to establish the order of tasks of an *intended* workflow of a lesson and supply information for some elements of the workflow; e.g., lesson goals and reading assignments.

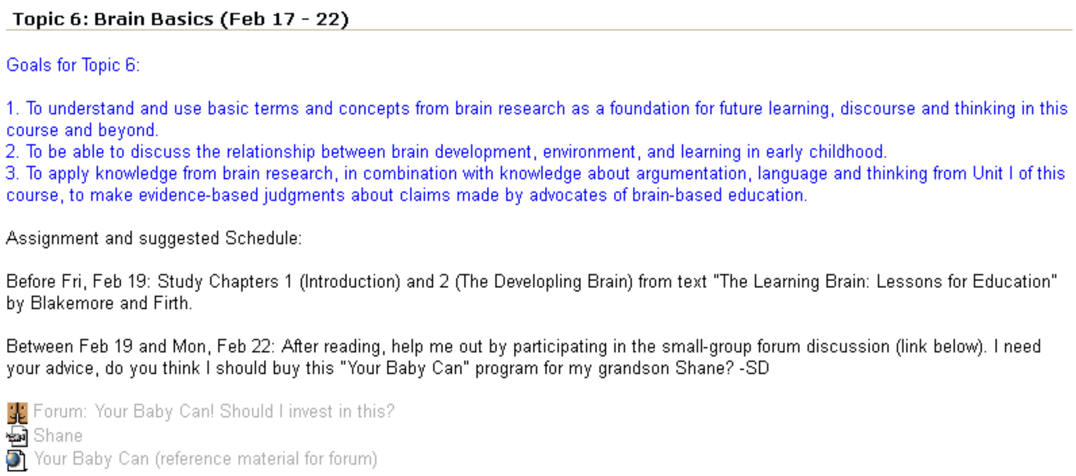


***Figure 9.* Screenshot of the HAL 'Brain Basics' lesson module posted on a course Moodle site.**

- Reports: The Moodle course management system (CMS) automatically creates a log record every time a person accesses a resource (i.e., video) or an activity (i.e., forum discussion). A 'Reports' tool allows a person with administrative rights to access this feature. The interface for the tool (see Figure 10) allows a user to view logs of activity or participation filtered on several dimensions - participant, date, activity, and action.

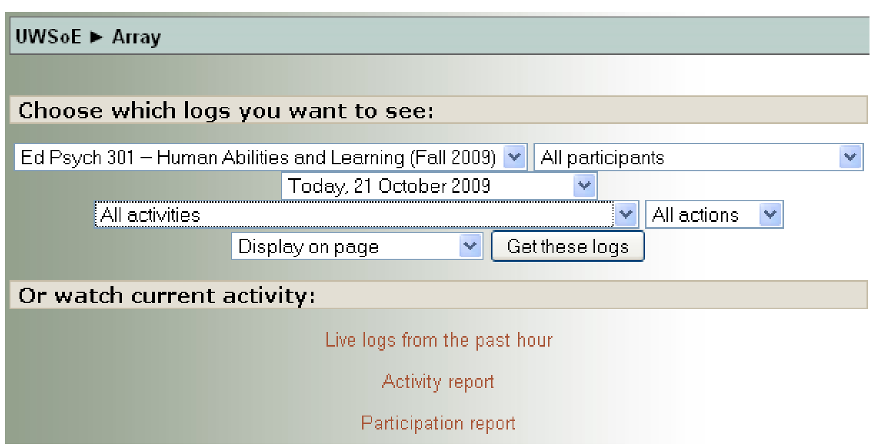


***Figure 10.* Moodle 'Reports' search interface.**

I "mined" data from the logs for the four week period of the unit for students in the targeted groups. Activity log data was used to create compliance charts (i.e., to what extent students actually accessed resources or participated in activities) and to build micro-workflows.

- Activity logs: Moodle organizes activities, i.e., forums (discussions), quizzes, resources and wikis, and provides a link to pages in which the data generated in the activity are listed chronologically in the order they were used/created. For example, clicking on a specific link on the Forum page gives access to all of the postings that were made to that discussion forum. These can be expanded in several views to show details of discussion threads. Forum data were mined for *instructions*, an element in macro-workflows, and *posts*, which appear as elements of micro-workflows. Quiz data were mined and associated with links in the unit assessment workflow.
- Blogs: As part of the unit assessment, after each unit students published a blog reflecting on what they had learned from that unit. The blogs of students in the target groups were mined and associated with links in the unit assessment workflow.
- Assessment Rubrics and Examples: The instructor provided students with links to the scoring rubrics used to assess students' forum contributions and reflective blogs, as well as examples of reflective blogs. These resources were obtained and became part of the lesson and unit assessment workflow elements.
- Face-to-face environment: From the course Moodle site I obtained copies of the resources used during the class session, including a PowerPoint presentation, a VMC video clip, and instructions for a problem-solving task. I followed prescribed procedures from "Guidelines for Conducting Video Research in the Learning Sciences" (Derry et al., 2010) to videotape the class using two cameras, one from a wide perspective and one focused on one group as they engage in the problem-solving task. IRB approval to

videotape was obtained prior to the class meeting and only images of students who signed an informed consent to be videotaped were captured. Care was taken to capture references to physical artifacts (i.e. Unifix cubes used in a small group mathematical problem solving task) and written representations in the group problem solving activities. Links to all the resources, artifacts, and the videos were made in the macro-workflow for the lesson "Understanding Children's Mathematical Thinking – Classroom".

Evaluation phase. The goal of the evaluation was to determine if the WVS is a viable tool for organizing intervention data into intermediate representations that support DBR and sharing of interventions.

Data sources. The primary data used to evaluate the WVS with respect to the research questions was the reaction of representative potential users to my presentations explaining the system to them. The subjects identified in Table 3 generated most data used for my evaluation.

Table 3. **Participants in the evaluation of the WVS.**

Name	**Description**
University of Wisconsin - Madison	
HAL-O design team	
Sharon Derry (SD)	Senior PI on the VMC Project; HAL course designer and instructor; senior researcher
Alan Hackbarth (AJH)	Designer of the WVS; project researcher; former teaching assistant (TA) for the course
Julia Gressick (JG)	Project researcher; former TA for the course
Brendan Egan (BE)	Project researcher; former TA for the course
Rutgers University	
Senior PI's	
Carolyn Maher (CM)	Senior-PI; course designer and instructor; senior researcher; director of Robert B. Davis Institute for Learning; produced the 22-year corpus of videos used in the VMC
Cindy Hmelo-Silver (CHS)	Senior-PI; course designer and instructor; senior researcher – problem-based & computer supported collaborative learning
Dan Zalles (DZ)	Senior researcher at SRI International Research Institute; VMC project evaluator

Project managers	
Marjory Palius (MP)	Co-PI; manages course scheduling, material distribution, assessment and data collection for all VMC project sites
Robert Sigley (RS)	Manages technical aspects of field projects – maintains course website(s), distributes video materials
Project instructor	
Judy Landis (JL)	Course designer; professional development instructor
Systems/software analyst	
Mike Kanarek (MK)	Graduate student; director of assessment in large urban school
Software Developers	
Chad Mills (ChM)	Programming coordinator for Rutgers Libraries; VM architect
Yao Yang (YY)	Database programmer

My approach was to give presentations (see Appendix A for presentation content) about my design work to subjects, who were grouped by their role in the VMC project, and record their responses on video- or audiotape. The collected responses of the subjects included reactionary comments or questions that arose during my presentation, similar to those encouraged in think-aloud protocols (Ericsson & Simon, 1983). Following presentations to Rutgers senior PIs and a teacher educator who was providing professional development at one of the Rutgers sites I asked them to complete a workflow-building task and I collected "think-aloud" data as they completed that tasks. I also interviewed all subjects following presentations to obtain reactions to my designs for the purpose of supporting design research and sharing of interventions. Instructions for the workflow building task and interview questions are shown in Appendix B. In the case of the analyst and software developers, in the interview I also collected comments related to future development of the tools to support wider use of the system.

For analysis I treated the responses by each group of subjects as individual cases (Yin, 2003). These are shown in Table 4:

***Table 4.* Cases of representative subjects' reaction to the WVS.**

Case: Rutgers VMC Senior PIs Meeting @ UW-Madison, July 26 (presentation) & July 29 (workflow task & interview), 2010			
Activity/(Time)	**Description/Goals**	**Participants**	**Setting/Equipment**
WVS interactive presentation (w/questions & discussion) (1:00)	Hackbarth presented WVS design concept to key potential users; situated WVS within goals of VMC project; described elements of workflow visualizations; demonstrated prototypes.	HAL-O team, DZ, CM, CHS	Conference room; video projector; digital voice recorder (DVR)
Workflow building task (:43)	Users used markers and stickers of workflow icons to construct representation of an intervention on poster paper, enabling developer to judge intuitive usability of system elements and other interface design features.	CM, CHS	Conference room; video projector; 2 digital video cameras; DVR
Interview (:44)	Researcher used questions in Appendix B as basis for gaining deeper understanding of users experience with interface and of user reactions to creating and using workflow visualizations for teaching, sharing, and research.	CM, CHS	Conference room; video projector; 2 digital video cameras; DVR
Case: Rutgers VMC Project Managers Meeting @ Rutgers University Graduate School of Education, August 16, 2010			
Activity/(Time)	**Description**	**Participants**	**Setting/Equipment**
WVS interactive presentation (1:30)	To explain WVS design concept to key category of potential users; situate WVS within goals of VMC project; describe elements of workflow visualizations; demonstrate prototypes. This presentation included discussion with participants of technical aspects of design of interest to management personnel.	MP, RS	Office suite meeting area; video projector; DVR
Interview (1:51)	Researcher used questions in Appendix B as basis for gaining deeper understanding user reactions to using workflow visualizations for teaching, sharing, research, and project management.	MP, RS	Office suite meeting area, video projector, DVR

Case: VMC Project Instructor Meeting @ Seaside (NJ), August 19, 2010			
Activity/(Time)	**Description**	**Participants**	**Setting/Equipment**
WVS interactive presentation (:55)	Same as above (Senior PIs)	JL (with MP present)	Home; bistro table; computer; DVR
Workflow building task (:50)	Same as above (Senior PIs)	JL	Home; bistro table; computer; DVR
Interview (:18)	Same as above (Senior PIs)	JL	Home; bistro table; computer; DVR
Case: Systems Analyst/Software Developers Meeting w/systems analyst @ RU Graduate School of Education, August 18, 2010 Meeting w/software developers @ RU Library Annex, August 20, 2010			
Activity/(Time)	**Description**	**Participants**	**Setting/Equipment**
Informal presentation/discussion (1:17)	Researcher and former IBM systems analyst discussed tool and how to train people to use it.	MK	Office suite meeting area; computer; DVR
Design session (2:10)	Researcher and software developers discussed how to implement workflow visualizations within VMC.	CdM, YY	Conference room; video projector; whiteboard; DVR

Additional data used in the evaluation of the system was generated during HAL-O research team meetings. From audiotapes of meetings I extracted discussion segments that were related to the WVS directly or to how the WVS supported evaluation of the HAL course. Course evaluation was the topic of one meeting in particular in which the WVS played a role in structuring the discussion by providing visualizations that revealed interesting patterns in students' participation and data that members pointed to as they made conjectures about potential modifications to the interventions. Because this meeting (and the discussions of the HAL-O research team in general) differed from other cases because it represented actual *in situ* use of the WVS, I chose to list it as a unique case separately here (Table 5).

***Table 5.* A case of HAL-O course evaluation as an evaluation of the WVS.**

Case: HAL-O Research Team Course Evaluation Regular Meeting @ UW-Madison, Ed Psych Building, June 22, 2010			
Activities/(Time)	**Description**	**Participants**	**Setting/Equipment**
Course evaluation and redesign (~:40)	Research group used WVS visualizations to facilitate a discussion of student participation in course activities	SD, AJH, JG, BE	6th floor conference room; video projector; blackboard; DVR

Data documentation. Data from meetings, interviews, and discussions were documented in the following ways:

- HAL-O meeting notes: Audiotapes of meetings were reviewed and relevant segments were transcribed. Field notes were annotated using audiotape data (i.e., time and data) (Richards, 2005; Yin, 2003). Logistical details of one particular meeting that is a case of the research team evaluating the HAL online course are shown in Table 5.
- Presentation transcripts: Presentations with VMC research group members were interactive; participants knew me and one another and were comfortable asking numerous (in quantity and scope) questions and freely sharing their observations, impressions, and recommendations. Presentation sessions lasted between one to one-and-a-half hours. Four presentation sessions were audiotaped and transcribed. My transcripts consisted of time, speaker, and utterance information. Utterances were transcribed *semi*-verbatim (http://www.effectivetranscription.com/FAQ.html#q3) – ums, uhs, false starts, repetitions, “you know”, “like”, and pauses were not transcribed. Overlapping speech (between two or more speakers) was annotated and actions related to an utterance (e.g., pointing to an object while talking about it) were noted. Affirmation utterances (i.e., “um-hum”, “yeah”, “okay”, or “right”) by one participant while another was were transcribed

with overlaps noted. I also rechecked each completed transcript and made corrections as necessary. This procedure was used for all transcriptions.

- Transcripts of workflow building task: Because this task required active involvement on the part of the researcher, I did not use the method of think-aloud protocols (Ericsson & Simon, 1993). Nevertheless, participants who built workflows did a great deal of talking about the exercise as they worked and their utterances were transcribed in the manner previously described. Along with giving instructions, I also did a lot of talking during the exercise. For example, as the recognized expert I explained how to use materials to interpret the meaning of icons, discussed the lessons they chose to represent with a workflow, helped choose and position icons, and explained the rationale for the way the icons were assembled into a workflow visualization. Two workflow building sessions, one with the Rutgers VMC senior PIs and the other with a VMC instructor, were recorded and transcribed. Logistical details of the workflow building tasks were listed previously as case activities in Table 4.
- Interview transcripts: As described in the previous ‘Tools’ section, interviews consisted of clusters of semi-structured questions around four main topics. Logistical details of the interviews were listed previously as case activities in Table 4. Depending on the role in the VMC project of the interviewee (i.e., designer, researcher, or teacher educator), different questions were emphasized, or interesting responses to questions were occasionally pursued for one group but not for another. As with the presentations, interviews were fairly interactive with interviewee’s occasionally asking me questions about the design or me offering explanations about design or development rationale in order to clarify or give context to a question. As noted above, each interview was

transcribed semi-verbatim. Interviews lasted approximately one-half to one-and-a-half hours. Four interviews were transcribed.

- Transcripts of discussion with VM software developers: The meeting with the VM software developers was, in part, to inform and coordinate my design work with theirs, and to speculate on emerging design and development issues. More specifically, we talked about building tools that allowed people to easily build workflow visualizations and automate the process of populating them with data. The meeting was approximately two hours long.

Role of researcher. As noted in the previous section, there were two environments in which data were collected for the evaluation phase of this study: HAL-O design team meetings, and presentation/workflow-building task/interview sessions with members of the Rutgers VMC research team. In both cases I was recognized as a member of the group, more centrally in the former; more peripherally in the latter.

HAL-O design team meetings. Merriam (1988, pp.92-93) notes that there are several stances one can assume while collecting information, ranging from complete observer to complete participant. In reality a researcher is rarely one or the other. As a participant-observer, "the researcher's observer activities, which are known to the group, are subordinate to the researcher's role as a participant in the processes of the group" (p. 92). At many times I took the role of participant-observer. For example, at many points in the research project I was called upon to perform researcher duties, including preparation of workflow visualizations to support analyses and sharing. However, especially during periods of data analysis related to course evaluation and redesign, my role in meetings shifted more to *observer-participant*, in which I attended to how other members used workflow visualizations to analyze course design and how that influenced changes.

Participant-observation includes caveats. Yin (1994, p. 89) identified several potential problems associated with participant-observation: the investigator may have to assume positions or advocacy roles contrary to the interests of good scientific practice; the participant-observer may become (too much of) a supporter of the group (or system) being studied; or the participant role may consume too much time – the observer-half may not have enough time to take notes or raise important questions. I do not believe these caveats applied strongly to my study. Although I presented my design work for feedback at research meetings, I was careful to not advocate for their use. During meetings that involved analysis and redesign, I participated minimally and primarily observed how the workflow visualizations *supported or influenced* analysis and redesign of a HAL unit of instruction. At no time was the group's research constructed as a competition to discover the best data collection and presentation tools; many different approaches were used and valued. Workflow visualizations were appropriated when useful, and I analyzed those appropriations, including researchers' requests for changes and their statements about the strengths and limits of my designs.

Rutgers VMC research group sessions. As noted previously, not all people or groups from Rutgers who contributed data to this study participated in all of the activities from which data was gathered. For example, the VMC project managers had relatively little lesson design experience but more technical experience than others; because they demonstrated during the presentation that they were sufficiently familiar with the design logic of the workflow visualizations I felt they did not need to do the workflow building task. The interview with the systems analyst was an impromptu meeting arranged by one of the senior PIs. Because he had a specialized expertise that I had an unexpected opportunity to tap, our session was more exploratory than the others; in that case I used the presentation slideshow and workflow website to scaffold a more free-formed interview. In the same way, the interview with software developers from Rutgers Libraries, with whom I had already discussed workflow visualizations before beginning this study, was mostly free-formed and centered on tool design.

It is important to note that as the designer of the WVS, the presenter, the guide for the workflow building task, and the interviewer, my knowledge, ideas, rationale, insights, and biases were ubiquitous in the data. Because of the collegial relationships I had with nearly all the participants, most were quite comfortable asking me questions about and offering critique of the WVS and my rationale or motivation for the design of particular aspects of the system. While I was again conscious of my role as a participant observer I also understood that I was asking them to make judgments about a system with which they had very little experience. I felt the benefit of answering questions related to my design rationale outweighed the risk of bias because it helped participants to feel more comfortable about commenting on the system because they had an opportunity to understand it more completely, and it allowed them to comment on the design rationale in addition to the system. Furthermore, the caveats about advocacy and amplified support for the WVS again don’t apply in these cases because there was not a competition of data presentation tools for the VMC. The project had previously committed to developing this tool. Thus the underlying bottom-line questions with the Rutgers VMC research group were essentially, how could you use this tool to share interventions and do research and how would you improve it?

Tools. The specific tools that were used for the WVS presentations, workflow building task, interviews and data collection included the following:

- PowerPoint Presentation/ Demonstration Website[4]: In each presentation I began by situating my design challenge within the broader project goals. I discussed key components of workflow design, critical elements of educational designs, and information design principles. I then moved to the project website and demonstrated all of the features of the workflow visualizations. The PowerPoint slides and screenshots of the website can be reviewed in Appendix A.
- Workflow Building Task/Interview Protocol: Appendix B is the interview protocol for researchers and teacher educators (Merriam, 1988; Yin, 2003). There are two parts to the protocol; the first is the interviewer's script that set up and guided the workflow building task that was completed by the Rutgers VMC senior PIs and project instructor, and the second is the interviewer's script for the semi-structured interview with the senior PI's, the VMC project managers, and the project instructor. The workflow building task was broken into seven parts. Throughout the exercise the macro-level workflow visualization for the "Brain Basics" lesson from HAL Online was used to illustrate aspects of the tasks that participants were asked to complete. They were given sheets of peel-off stickers that contained copies of all the WVS icons and asked to:
    1. Select an intervention they have used in the past and write a brief description.
    2. Identify tasks completed by students during the intervention, find stickers corresponding to those tasks, and tentatively arrange them in a recommended order of completion.
    3. Use a marker to draw connectors between to show the intended flow of the intervention.

[4] The presentation was also given at ICLS 2010; however no data were collected there.

4. Write a very brief identifying description next to each task and the Workspace icon. Add the suggested time for each task.
5. Add stickers that visually identify the general input for each task and write the specific name of the input.
6. If not obvious, write a brief description of the roles of students, teachers, or others next to each task icon.
7. Identify the tasks where data will be generated and place an output sticker by the task that gives a visual general description of the output. Write a summary of specific details about the output on the sticker.

The interview with the senior PI's and instructor followed immediately after the workflow building task. In the case of the project managers, the order was presentation, lunch break, and interview. Interview questions addressed user reactions to four issues: usability of the user interface; the WVS as a tool for instructional design and sharing; the WVS as a tool for design research; and recommended next steps in the WVS development. As much as possible I tried to avoid asking questions that could be answered with a yes or no. Most questions started with prompts that solicited opinion or the need for richer explanations; e.g., "What was your initial impression…", "What is your opinion of…", "What would be a more useful way…", and "How would you…" (Merriam, 1988; Yin, 2003). In the cases where I did ask questions with yes/no answers I included follow-up questions such as, "Why do you say…", and "Give me an example of…".

- Workflow Icon Stickers: All of the icons – control elements, tasks, inputs and outputs – were printed on adhesive label sheets to be used by the senior PIs and instructor who did the workflow building task. Multiple copies of every icon were printed.
- Data collection tools: Meetings, presentations, workflow building tasks, and interviews were audiotaped with a digital voice recorder or videotaped with two digital cameras (Richards, 2005). All audio files and videotaped sessions were downloaded to my computer with copies stored on a secure server at the Wisconsin Center for Education Research (WCER) (Richards, 2005; Yin, 2003). All interviews were transcribed and copies of the transcripts were printed out and assembled in a binder for coding and other analyses. Multiple digital copies of the transcriptions were kept on my computer, on a flash drive, and on the WCER secure server (Richards, 2005). Field notes were taken by pen and paper and converted to Word documents. The workflow representations completed by the Rutgers senior VMC PI's and the instructor were collected and photographed.

Analysis

Case study methodology. To analyze the data collected in the evaluation phase, I used *case study* methodology (Merriam, 1988; Stake, 2003; Yin, 2003). Yin contrasts several major research strategies in the social sciences (i.e., experiments, surveys, archival analysis, histories, and case studies) according to three conditions; (a) the type of questions posed, (b) the extent of control an investigator has over actual behavioral events, and (c) the degree of focus on contemporary as opposed to historical events. Case study is an appropriate methodology when "how" and "why" explanatory questions are asked about contemporary events, and where relevant behaviors of players in the system cannot be manipulated. Merriam (1988, p. 9) and

Stake (2003, p. 135) cite a fourth factor in deciding on case study as an appropriate research design – whether a *bounded system* (i.e., program, person, process, institution, or social group) can be identified as the focus of the investigation. These criteria are characteristic of both the HAL-O design team's evaluation of the designed unit of the HAL Online course and to my meetings with Rutgers VMC research team members. My "how" and "why" research (and interview) questions focused on the usefulness of prototype visualizations that were products of a bounded system. By controlling the content of the presentation and suggesting possible configurations for lesson elements in the workflow building exercise I did have some degree of control over how subjects understood the WVS. But I had little or no control over how the HAL-O team chose to use it in the evaluation of HAL Online or speculation by the Rutgers personnel of its usefulness or how they might use it in their own work.

As noted earlier I organized the data from several meetings into five case studies. All five cases arguably fit Stake's (2003) definition of *instrumental case studies*: "The case is of secondary interest, it plays a supportive role, and it facilitates our understanding of something else." Stake notes that the case is still looked at in depth, but because it helps the researcher to pursue the external interest, the choice of case is made to advance understanding of the other interest (p. 137). In the HAL course evaluation case, I used the evaluation of the course to gain understanding of how the WVS might support DBR. The Rutgers VMC research members were asked to think about and describe samples of their own research or instruction in terms of the WVS so that I could better understand how the my WVS could be adapted to support a broader scope of work beyond the context in which it was developed.

The analytic technique I used with the case study data generated by the Rutgers VMC research group was an adaptation of Yin's (2003) idea of *explanation building* as it applies to an explanatory case study methodology. According to Yin, explanation building is an analytic strategy that employs a special type of pattern-matching logic to compare empirically based patterns with predicted ones to build an explanation about the case. To “explain” a phenomenon is to stipulate a presumed set of causal links about it that may be complex and difficult to measure in any precise manner (p. 120). He notes that in most cases explanation building has occurred in narrative form and because narratives cannot be precise, the better case studies are the ones in which the explanations have reflected some theoretically significant propositions. Yin (pp. 111-112) writes, “The original objectives and design of the case study presumably were based on such propositions, which in turn reflected a set of research questions, reviews of the literature, and new insights. The propositions would have shaped the data collection plan and therefore would have given priorities to the relevant analytic strategies.” Table 6 shows the alignment of the research questions that guided this study with their various theory-based frameworks, initial design hypotheses, tasks and interview questions that were performed or asked in the evaluation phase of the study, and the data sources produced by those tasks and questions.

***Table 6.* Alignment of research questions with theoretical bases of the study, data collection/tasks, and data sources.**

Research questions related to:			
Range of representation	Complexity of representation	Usefulness of visualizations	Generalizability of system
What elements/variables of a designed intervention are important to represent in a workflow visualization, and what are their relationships?	**How is *context* of an intervention represented in a workflow visualization? What level of *abstraction* needs to occur in order to support generalization (and reuse) of workflows, or elements of workflows?**	**How does the WVS show potential to solve problems of control and efficiency in design-based research? How are differences captured in interventions that may lead to theory-based explanations or changes in outcomes?**	**How can the WVS be adapted to other contexts, e.g., face-to-face classes or short-duration professional development seminars? What changes need to be made to the WVS in the next design cycle as a result of evaluation?**
Theoretical basis			
• SIF • WMC key perspectives • Activity Theory (AT)	• Info. Visualization literature • Workflow literature • AT (as counterexample)	• Info. Visualization literature • Design-based research	• Workflow literature (i.e., scientific workflow idea of reuse)
Design hypothesis			
• A visualization needs to show specific goals, tasks, the inputs associated with each task, outputs generated, participation structures, time, workspace description, and assessment information. • The SIF, AT and WMC all define c*ategories* (some that overlap) that each contain multiple elements, e.g., participant structures may be a student, a group, or the whole class. Relationships of elements /variables are determined by the relation of these categories to one another, e.g., subjects act on objects using tools.	• Context is accounted for at the macro-level by pairing specific resource information with each general icon. Sub-workflows contain context specific information that is related to a performance task, and micro-workflows present student and group specific data. • A level of abstraction that allows a viewer to see and manipulate individual elements of the design (i.e., change order or resources, add/subtract elements,) irrespective of specific context is needed to support reuse and generalization.	• A workflow visualization facilitates a level of control by making explicit the connections of all elements to one another and to associated resources. • Information is layered to be displayed in one screen, which makes access to data efficient. • Differences from deliberate design changes are captured as structural difference in the workflows and corresponding data. Differences across groups that are the result of spontaneous design change may be captured by a change in intervention data.	• Creating visualizations of face-to-face environments presents data collection challenges. Tools have to be developed, or protocols developed with tools such as digital cameras, scanners, or cell phones that allow instructors and students to easily create and upload digital traces of the things they do in the intervention. • The greatest changes to the WVS will be to automate the processes of creating workflow visualizations and populating them with data.

Table 6 (continued).

Related interview questions/tasks			
• What is your opinion of the current collection of icons (that are intended to describe the elements of the lesson)? What's missing? • Would you want a "build-your-own-icon" feature?	• The workflow building task gives senior PI's and instructors experience with the levels of abstraction built into the icons and methodology. • What do you think of the macro-workflows in terms of display of information? Sub-workflows? Micro-workflows? • What caveats would you need to include if you were going to use workflow visualizations to share interventions?	• What is your opinion of the current levels of information accessibility/display? • What kinds of research tasks could be supported with workflow representations? What would make it a more useful research tool? • Comparison of Spring '10 and Fall '10 HAL Online implementation of 'Early Brain Development' lesson	• Workflow building task w/ a teacher educator; (used stickers to build a workflow representation of a day-long lesson with inservice middle school teachers.) • Discussion w/software developers re: how to facilitate easier data collection from face-to-face environments. • What features would you want a tool that builds workflow representations to have?
Data Sources			
• Transcripts of presentations and interviews with Rutgers senior PIs, project managers, and project instructor. • Transcripts of workflow building task done by Rutgers senior PIs and project instructor. • Transcript from HAL-O research team meetings. • Field notes from HAL-O research team meetings.	• Same as previous column	• Transcripts of research team discussions related to comparison across semesters. • Field notes from HAL-O research team meetings. • Workflow visualizations of the two lessons; Spring '10 and Fall '10..	• Transcripts of presentation, workflow building task, and interview with project instructor. • Transcript of meeting w/software developers. • Transcript of meeting w/software analyst. • Field notes from HAL-O research team meetings.

An important characteristic of the explanation-building process is that the final explanation is a result of a series of iterations as follows:

- Make initial theoretical-based statements about the object of study.
- Compare the findings of an initial case against the statement(s).
- Revise the statement(s).
- Compare other details of the case against the revision.
- Revise.
- Compare the revision to the facts of a second, third, or more cases.

The gradual building of an explanation is similar to the iterative process of refining a set of ideas (Engle, Conant, & Greeno, 2007; Yin, 2003), in which an important aspect is to entertain other plausible or rival explanations. The plausible or rival ideas emerged from the data collected in the Rutgers VMC team case studies.

Using explanation building as a model, my analytic technique was to develop theoretical hypotheses related to my research questions that taken together explained how WVS-produced workflow visualizations are intermediate representations that support DBR and sharing of interventions. I developed a presentation in which I gave this explanation to a sample of representative potential users, a workflow-building task in which selected potential users experienced the process of building a workflow visualization, and an interview protocol in which I directly asked potential users for their reaction to the specific elements of the WVS that they saw in the presentation or experienced when doing the workflow building task. Where my analysis diverged from Yin's suggested protocol is that I did not revise my propositions after the initial case. Instead, due to time and logistical constraints that required me to collect data on all cases within a limited timeframe, I simply noted potential revisions and proceeded to the next cases. Each subsequent case either reinforced a potential revision or introduced a new one. The intent was that this study would produce design recommendations for the next cycle of development of the WVS.

Coding. After transcribing I developed three sets of categorical codes for interviews, presentations, and simulations (Richards, 2005). Codes for the interview were derived from the four categories of interview questions (see *Interview Questions* in Appendix B) which were:

- User interface
- Instructional design and sharing
- Research
- Next steps
- General comments, observations, or questions

For both the presentation and the simulation I initially read a transcript and identified tentative codes that related to the descriptive or functional features of a workflow visualization, for example, comments or questions about the meaning of an icon or if information should appear in response to a mouse-over or a click of an icon. I then refined the emergent codes by applying them to another transcript, and later recoded the original transcript using the refined codes. The codes for each type of transcript are listed below:

- <u>Presentations</u> - things that were talked about, asked about or commented on:
    - Structure of workflow and workflow elements (i.e., icons)
    - Workflow perspectives (i.e., SIF, AT, WMC perspectives)
    - Information visualization features
    - Specific prototype contextual features
    - Intended versus actual workflow

- Simulations – instructions, questions, and observations while building a workflow:
    - Strategy (for building workflow)
    - General structure of the workflow (i.e., arrangement of tasks)
    - User interface (i.e., selection of icons)
    - Contextual elements of the workflow (i.e. actual resources used or data created)
    - General comments, observations, or questions

The codes were used to identify and categorize comments, questions, suggestions or objections in the transcripts with related aspects of the WVS design or prototype implementation. For each case I identified and marked instances of each code in the transcript and kept a log with notes about how the utterance(s) related to my explanation of the WVS (Richards, 2005; Yin, 2003). As I reviewed the coded transcripts and notes for each case, common reactions or themes arose both across activities within each case (i.e., presentation, workflow building task, or interview) and across cases. The themes that arose from coding the transcripts are reported in the following chapter.

IV. Results

Overview

In this chapter I will first describe how a synthesis of ideas from the literature on design research, information visualization, business and scientific workflows, and workflow mining led to the design, development, initial evaluation, and redesign and development of prototype workflow visualizations. Following that, I will report results of case studies with members of the VMC project team from Rutgers University in which they were presented the visualizations and asked if/how the methodology could be applied in the contexts of their design work and research. They also provided feedback on how the visualizations and tools could be improved in the next design iteration. Included in these cases is a synthesis of technical discussions with a former IBM systems analyst and two software developers from Rutgers Libraries. I finish with a case of how workflow visualizations informed redesign of aspects of HAL Online lessons, and show before and after visual comparisons of a redesigned lesson.

Initial Design and Development of the WVS

Producing the initial macro-workflow expression (WVS 1.1). To explore the efficacy of the graphical elements of the ICN workflow modeling language to represent a learning environment, I recovered archived data from a HAL Online lesson titled “Adventures in Argument” and created a “digital sketch” of the intended workflow. Data came from a Moodle module that listed instructions, resources, including videos of residents and developers in two desert communities arguing about scarce water resources, and a discussion forum. There was also a suggested order in which students could independently view the resources and complete the discussion in small groups. Additional data in the form of instructions to students was mined from the online discussion module for the lesson. The product that resulted from this initial exercise was a workflow representation of the lesson tasks, which is highlighted with bold circles and connecting lines in Figure 11. A lexicon for the symbols used in the workflow representation is given in a previous chapter (Table 2).

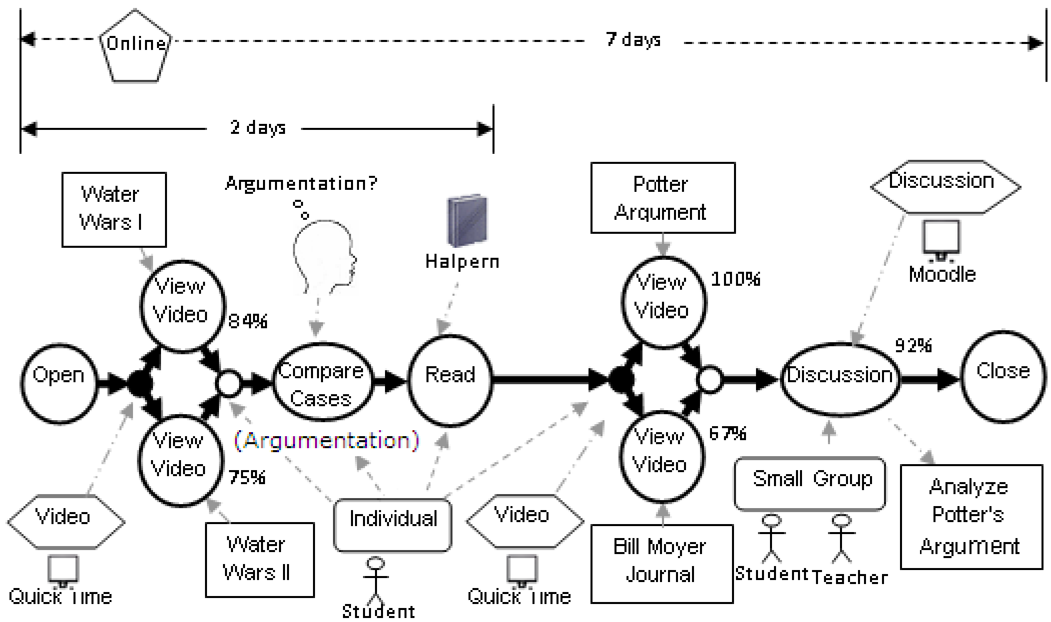


Figure 11. **An intermediate workflow representation of the 'Adventures in Argument' lesson.**

In the workflow representation for this particular lesson two instances of branching (of two video-viewing tasks) are shown. Visually, the lesson "flow" splits at a closed dot (that symbolizes that both tasks are meant to be completed before moving on to other lesson tasks and that the order they are to be done doesn't matter). The open dots (a *merge*) that rejoin the branches indicate that the workflow may continue before accomplishing both preceding tasks. Using data from the lesson module and the logs I also added repositories (represented as rectangles) to the workflow expression. *Consumption* relationships (with arrows pointed *toward* activity circles) involve tasks such as watching videos while a *production* relationship (with arrow pointed *away* from the activity circle) occurs, for example, when students contribute to a discussion forum. In the same manner I added ICN elements that describe process data; videos were served by a digital video application (i.e., Quick Time) and the discussion took place in "cyberspace" (i.e., Moodle forum). "Individual" and "small group" roles were described and attributed to tasks in the manner (i.e., rounded rectangles and stick figures) specified in the ICN workflow modeling language (Rembert, 2006). I experimented with new icons to represent special kinds of repositories; the *silhouette* represents prior knowledge – in this case what students know about argumentation – which is activated and "consumed" by the reflection activity. The *book icon* represents consumable knowledge in the text book. I realized that the neither time or the type of workspace in which the activities occurs was represented so I tentatively selected a pentagon-shaped icon to identify workspace and arrowed lines to represent time (solid-line means '*must* be completed in this time'[5]; dashed-line means 'to be completed in this time frame'). Compliance data about how many students accessed lesson resources and tools was recovered from Moodle activity logs, calculated as percentages, and printed near each task circle. Two tasks - "Compare Cases (Argumentation)" and "Read" – do not show compliance data because students were not asked to generate data about their case comparison and the text they read did not come from the Moodle site.

I now discuss two major design decisions resulted from the presentation and discussion of this initial workflow sketch at research team meetings. The first was to extend the methodology to include micro-workflow expressions, and the second was to revise the macro-workflow expression to better represent the conceptual structures of the lesson.

Micro-workflow representation (WVS1.2). Discussions with the research group during vetting of the initial macro-workflow representation raised two important questions; 1) what is the appropriate level of granularity for an educational workflow representation, e.g.,

[5] However there is no explicit consequence in this case for failing to complete the tasks within the time frame.

implementation level or level of individual students, and 2) how should activities that include social interaction, i.e., discussions or group problem solving, be represented?

A macro-workflow representation such as depicted in Figure 11 shows the implementation level of a designed intervention, both the intended implementation, and aspects of the actual implementation (i.e., compliance). Macro-workflow representations facilitate a number of functions: sharing of adaptable interventions; quickly identifying resources, application types and participant structure at a systemic level; quickly identifying compliance of students' engagement with respect to assigned activities; and control by the designer of the overall implementation when contemplating design changes. However, one function the team discussed as valuable to design-based research that was *not* inherent in the macro-workflows, was an ability to see what individual students were doing during implementation of an intervention, and how students were interacting with one another in collaborative activities. These interactions with course resources and with each other are a usual part of educational designs and may influence modifications that get made to both the intervention's design and its grounding theories. Inspired by the examples of representations discussed earlier (Eberbach & Bernstein, 2009; Hmelo-Silver et al., 2008; Wortham, 2008) that supported finer-grained analyses, I developed a procedure for deriving a representation of student-resource and student-student-instructor interactions from CMS data:

1. Establish a master timeline that spans all of the actions that occurred within the province of the activity.
2. Mine the Moodle activity logs of individual students to determine which actions each engaged in and in what sequence (*control flow*). Express the sequence of actions on individual timelines aligned with the master.

3. Mine the content of the Moodle discussion forum to recover *data flow*: when was new data produced, and from where did discussants get the data that they responded to? Data flow is shown with notation (X.Y where X indicates a distinct thread and Y indicates a sequential post to that thread) and dashed lines that connect postings in a thread. [This sketch is limited in scope; for example, the individual timelines don't show when videos were viewed or the text was read.]

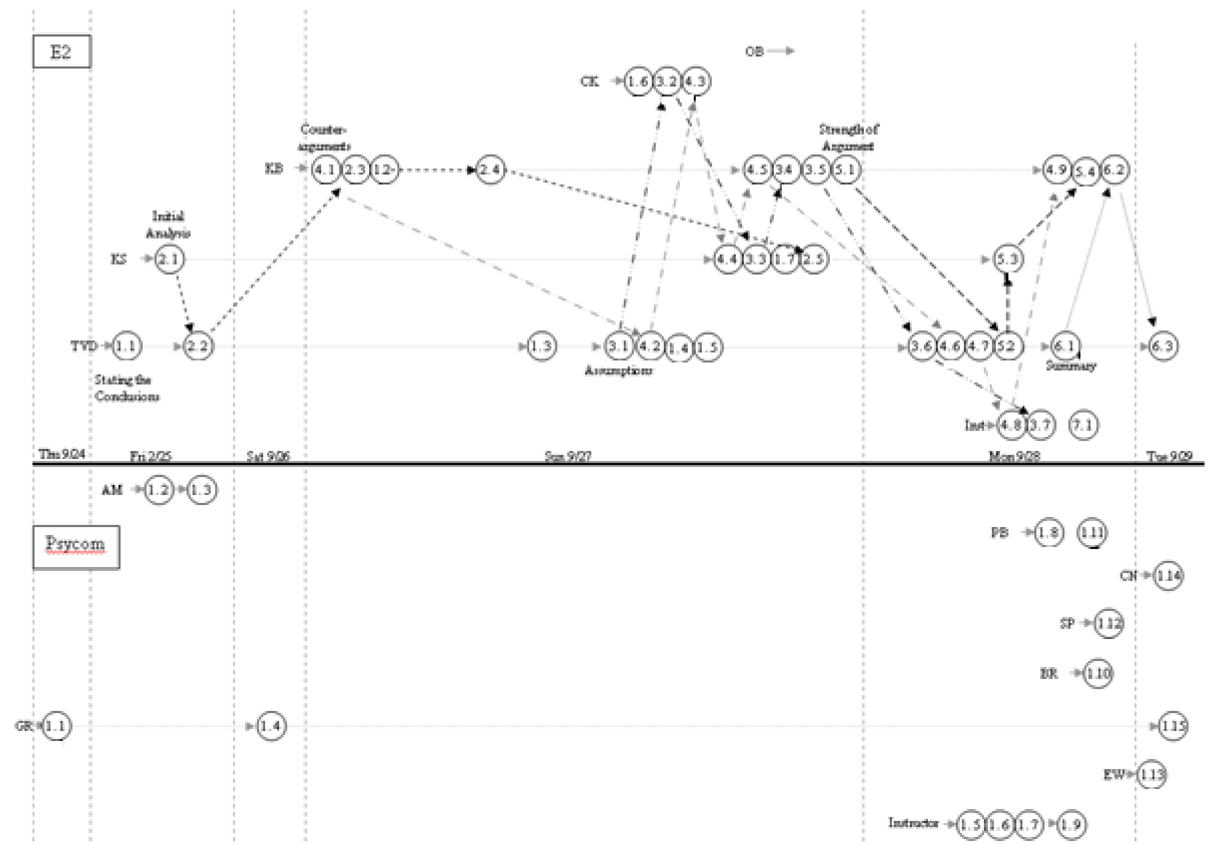


Figure 12. **A micro-workflow representation for the discussion task in the 'Adventures in Argument' workflow.**

The resulting *micro-workflow representation* (Figure 12) incorporates characteristics from each of the previously described tools – the ability to represent the interactions of many types of variables (Hmelo-Silver et al., 2008), separate timelines for individuals arranged in a way to display group interactions (Wortham, 2008), and the use of symbols to convey information about elements of an intervention (Eberbach & Bernstein, 2009). In this example the representation provides visual information about twelve individuals' discussion activity in a HAL Online lesson, and a comparison of two groups (separated by a bold timeline). The group interactions are represented as the discussion threads they created during the forums and the posts each student made to each thread. A viewer can immediately observe stark differences between the groups, interesting temporal patterns in terms of when individual students make posts, and patterns in the way that information in threads is picked up and acted on by different group members. These informal, quick analyses can help direct and focus subsequent deeper analyses, as well as the possible redesign of elements of the lesson. But, at this point, this representation was rendered as a static diagram on paper, which constrains the number and types of visual techniques that can be used to enrich the representation.

Alternate design of the macro-workflow representation (WVS 1.3). The graphical elements of the ICN workflow modeling language proved useful for capturing the *business-like* aspects of the learning environment. What it failed to capture was the "know-how" that is tacit in the design and execution of the lesson that is a primary characteristic of the scientific perspective of workflows. Designed lessons have a pedagogical rationale: reasons why a teacher has students watch a particular video or study a particular problem solution, or do these activities in a particular order. The value of a workflow representation would increase if it revealed the conceptual structure (or pedagogical schema) of activities that could be easily reused or shared.

To rethink the structure of an *education-specific* workflow I went back to the basic workflow unit – data is input, a process is performed, and data is output – and used that as a guide to redesign the workflow representation. I isolated inputs and separated them according to where they were used in the lesson. Then I identified the processes that were designed to occur in the lesson and described diagrammatically how inputs and tasks were mapped to accomplish the process. Particularly challenging to the idea of workflow is that while lessons are often designed so that the outcome of one process (e.g., contrasting cases) serves as input for another process (e.g., online discussion), it may happen that the conceptual understanding that a process is designed to develop is not completely formed when a student is asked to use it to do another activity. Often students need to revisit and redo or complete an activity in order to reinforce or increase their understanding of needed concepts or procedures. This back-channeling needs to be represented in the workflow representation. Finally summative outputs are produced that may be sources for finer analysis of the outcomes of a lesson, sometimes well after the lesson has concluded (e.g., end-of-unit reflection or quiz).

Taking all this into consideration and integrating suggestions for visual elements from research team members over several meetings, I designed an alternate macro-workflow representation for the "Adventures in Arguments" lesson shown in Figure 13.

The workflow representation is displayed in three horizontal panels. Each panel displays distinct elements of the lesson design that can be distinguished as either: (a) specific to the represented lesson; or (b) a generalized structure that can be modified and reused in other contexts.

The *Inputs* panel shows specific resources that were used in this designed lesson and also indicates from where those resources were retrieved. Separating resources from processes conveys the idea that resources can change from one instantiation of a lesson to the next while the lesson structure can remain unchanged.

The *Processes* panel is the heart of the workflow expression and depicts the organization of content acquisition and performance tasks designed to help students to accomplish the lesson goals.

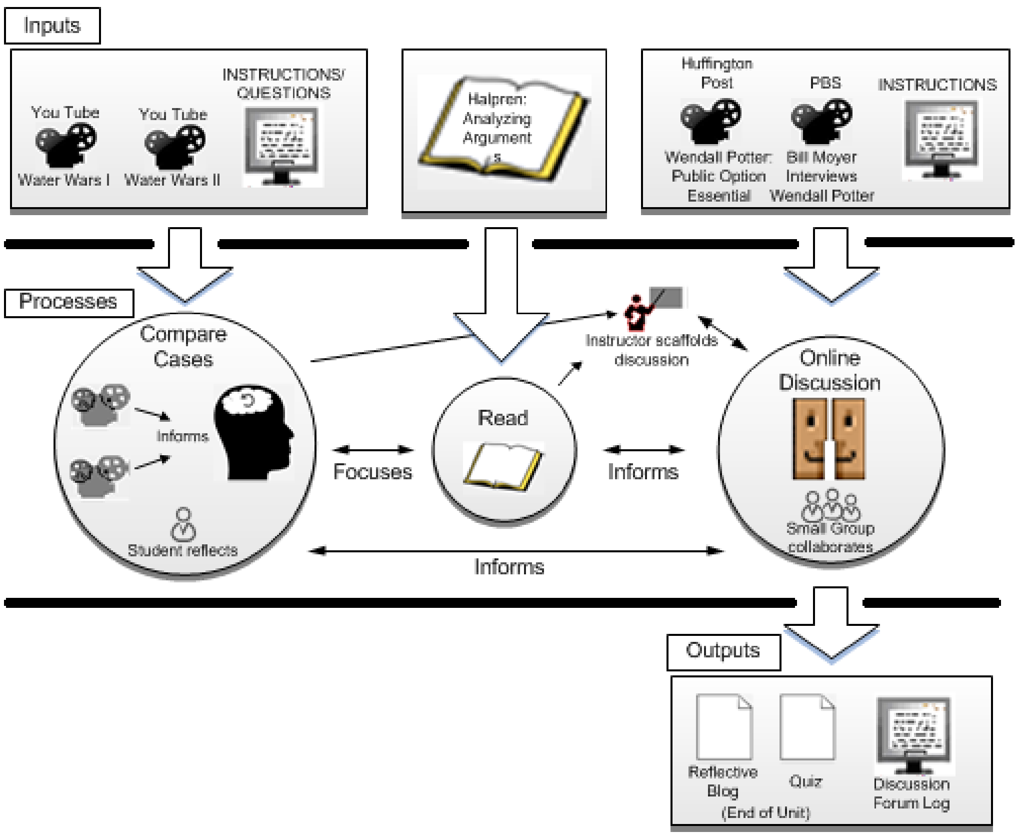


***Figure 13.* Alternate three-section macro-workflow representation.**

For example, in the first of two major lesson activities, individual students watch video (content acquisition) and mentally compare/contrast two sides of an argument (performance). This activity theoretically helps them to focus on the assigned reading and later informs a group analysis of a different argument. But these are not linear activities; students may go back and forth between the assigned reading and either set of videos in order to make sense of or correctly use important concepts. Finally, the instructor is an active participant in the group process of online discussion in that s/he may contribute postings that point to key concepts in the text, the previous activity, or in other group discussions. This relation is also represented by connecting arrows. Note that the resource icons (video, text) in the Processes panel are deliberately left blank to show that while particular kinds of resources (i.e., video) provide the cases that students compare or analyze, the choice of the actual resources can be adapted in different contexts. This is a step closer to discovering generalized representations for pedagogical processes that communicate standardized lesson structures regardless of content.

The *Output* panel includes the tangible products of the students' participation in the lesson. In this example these include the log of the online discussion as well as placeholders for students' reflective blogs and end-of-unit quiz. An important function of elements in the Output panel is to provide data and the means to do an assessment of the intervention. In Figure 13 sources of data are shown, but there should also be a link to the actual assessment instruments, along with scoring guides and rubrics, and actual data about student performance.

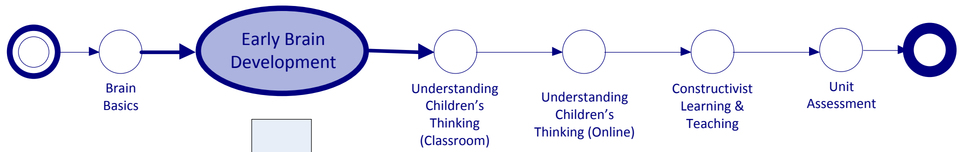
Summary of WVS 1.0 design cycle. The initial sketches are products of a "messing about" phase of my work where I familiarized myself with the concepts, tools, and challenges of the study. The products of the WVS 1.0 cycle were three workflow designs. The first (WVS 1.1) was a business-oriented model that favored the identification and the intended ordering of tasks to accomplish intervention goals. The second (WVS 1.2) was a finer-grained micro-workflow structure that tracked individuals *actual* path through a lesson (including skips, reversals, and returns), and aggregated individual timelines in a way that showed group interactions. The third workflow (WVS 1.3) was a product of vetting WVS 1.1 with the HAL-O research team. It emphasized aspect of workflow privileged by the scientific community; primarily the explicit representation of generalized knowledge structures of the domain (in this case, conceptual or pedagogical) that facilitated sharing and reuse.

WVS 2.0: A prototype *online* workflow visualization system. The first challenge for the WVS 2.0 design cycle was to design a model that integrated the two WVS 1.0 macro-workflow designs and retained the primary characteristics of each. The second challenge was to migrate from static sketches to web pages and write scripts to initially hide layers of information and then reveal it as a viewer moves the mouse over or clicks on workflow icons.

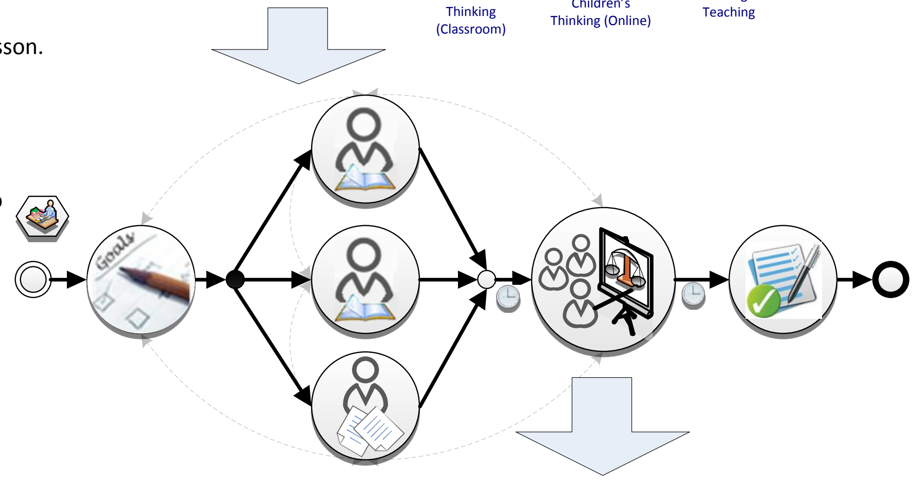
In WVS 2.0 a workflow visualization consists of several hierarchical levels. The base or macro-level prototype workflow visualization is at the lesson level. One level higher instructional *unit*-workflows are composed of *x* number of lessons that contribute to a more comprehensive set of learning objectives. At a lower level, each *task* or *activity* in a lesson contributes to the accomplishment of a goal(s); the outcome of a task may be the goal itself, or it may be a necessary piece needed to achieve a goal. At a lower level still, *tools* that match the conditions of a task are needed to do the task. And of course *people* use tools to do tasks, or may be tools (i.e., human resources) that help others do tasks.

I accounted for these levels and all these elements in the workflow visualization system with designs for a *unit workflow* and a collection of individual element icons that get combined into lesson-level *macro-workflows*, *sub-workflows* (which show the organization of multi-part performance tasks), and learner-level *micro-workflows*. Functional prototypes of these can be accessed and explored at http://vmc.wceruw.org/workflow/workflow.html. Workflows are either shown initially in a browser window when a user selects a lesson (as is the case with unit and lesson-level workflows) or are activated when the user mouses-over or clicks on an embedded link. The levels and their relations to one another are show in Figure 14, which is a partially exploded representation of a current WVS visualization.

UNIT LEVEL
Places a lesson in the context of a broader unit of instruction. Clicking on a lesson circle opens that lesson.



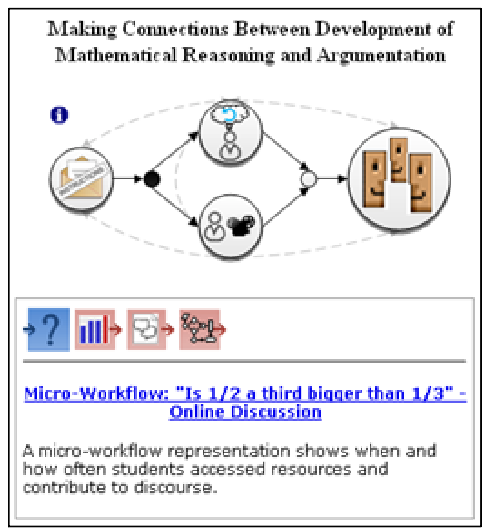
LESSON LEVEL
A lesson is displayed as a flow of tasks designed to accomplish an instruction goal. Task icons are links that reveal additional information when moused-over or clicked.



SUB-WORKFLOW LEVEL
Opens when user clicks on some task icons in the lesson workflow that have sub-tasks. Displays as a "mini" workflow. Mousing over different icons in the representation causes different information to be displayed in the information window below.

Some windows contain input and output icons. Mousing over an icon changes the display in the window.

Some description include hyperlinks that, when clicked, provide additional information.



MICRO-WORKFLOW LEVEL
Displays information about how individual students access resources, and about how groups interact.

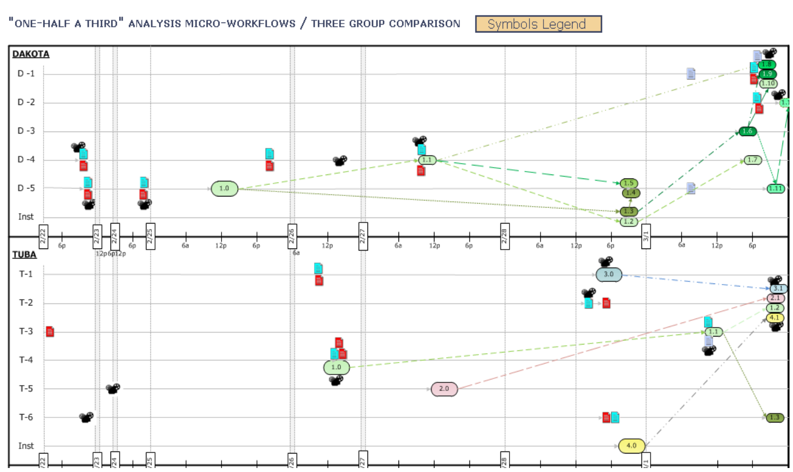


***Figure 14*. Multiple levels of information and data included in a workflow visualization.**

Unit workflow. The unit workflow had the easiest structure to visually represent; a unit has objectives, a finite number of lessons, and end-of-unit assessments. As a representation, I adopted a number line metaphor. As a *visualization*, which implies a degree of interactivity, the unit workflow will serve as a navigation tool for all other points. When a user clicks on the lesson or assessment points, s/he will open a new lesson (or assessment) level workflow visualization.

Element icons[6]. Creating descriptive visual icons was my solution for integrating domain-related information about tasks into the business-like "order-and flow" representation. The general formula for building icons for the WVS is illustrated in Figure 15 with a *task* icon; start with a shape to represent the category and add images that are descriptive of the particular participants and action in a task or information/data in a repository.

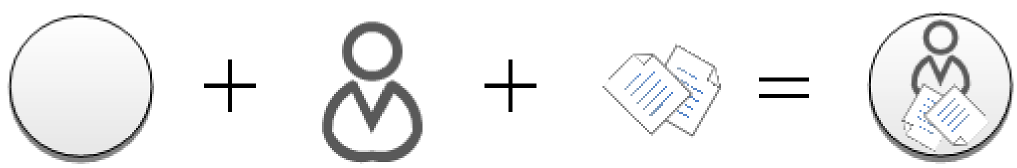
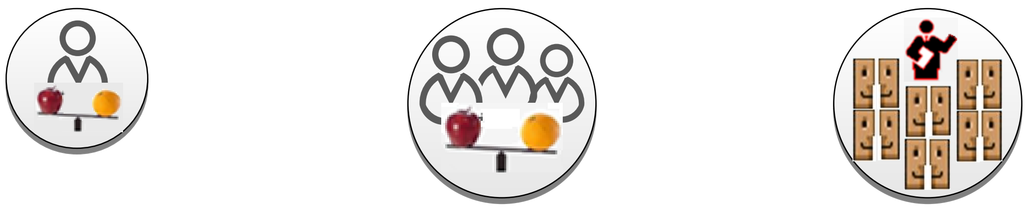


***Figure 15.* The general formula for building a WVS icon.**

In Figure 15 the icon represents an individual student reading an article. I started with a circle, the shape that represents a *task* in the ICN workflow language, then added a single generic person symbol and the standard icon for "document" (or two document icons to indicate a multi-page article), and arranged them so that the resulting figure can be interpreted as, "Task: Individual student reading a document." The finished icon has both task and subject/role elements – *what* is being done and by *whom*. So the shape provides a cue as to the category

[6] I use *icon* here to mean "a sign or representation that stands for its object by virtue of a resemblance or analogy to it," recognizing that the resemblance or analogy that I intend may not be readily apparent to the viewer. Still, the intent is that, with practice using the WVS the representations will become iconic.

(task) and a *micro reading* provides visual cues about the element. For some icons I used another easily detectable visual feature, *size*, to help viewers: 1) make distinctions between individual and group participation structures, and 2) distinguish potential multi-part tasks that may have sub-workflows. Figure 16 shows three task icons of different size and content.



(a) (b) (c)

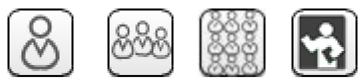
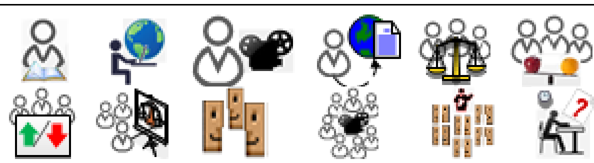
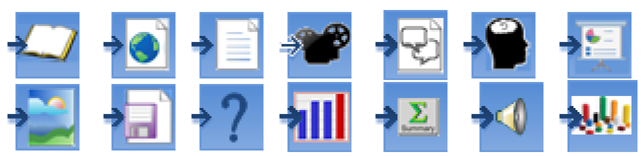
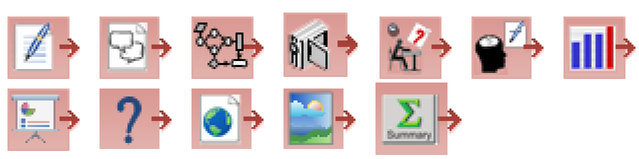
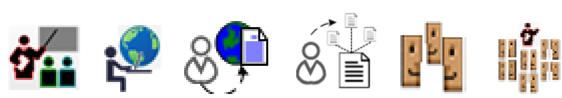
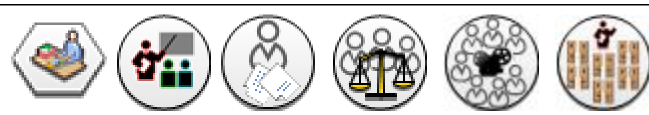
***Figure 16.* Tasks icons that show different participation structures of content.**

Panel (a) shows an individual student doing a comparison task. Panel (b) also shows a comparison task, this time conducted by a small group; in my icons three person figures represent "small group." The difference in size is intentional; "bigger" connotes *more,* as in "*more* people" and "*more* interaction" and possibly "*more* steps to complete the task." Panel (c) shows a whole group task; a discussion led by an instructor. The icon takes advantage of a standard discussion image and depicts a distinct authority figure as instructor. I chose not to make a size distinction between "small group" and "whole group".

Relation to theoretical frameworks. WVS icons are not just visual descriptions of tasks, inputs, and outputs. I derived elements for the WVS icons from reflection on two theoretical frameworks – the WMC perspectives on workflow representation (Hollingsworth, 1995) and variables of Bielaczyc's SIF (2006). Table 7 shows my proposed alignment and categorization of WMC perspectives, icons and symbols designed for the WVS, and SIF variables. It should be noted that while each theoretical framework aligns with collections of icons or symbols the frameworks do not necessarily align with one another. For example, in row 4 of the table the

informational perspective does not align with the ***beliefs*** dimension even though each is categorized with output icons.

***Table 7*. Alignment and categorization of WVS icons and symbols with theoretical frameworks.**

WMC perspectives	**Associated Workflow Elements** (Example icons for each category)	***SIF dimensions/ variables***
Organizational; *who* or *what* performs a task		Teacher; students; groups
Resource; *what* is used to complete a task		Knowledge, Affordances of workspaces, resources, and technology
Functional; *what* tasks or activity must occur		Intervention activities and associated resources
Informational; *which* data is processed and the *data flow*		Beliefs about learning and knowledge (inferred from assigned tasks and student output)
Organizational; *who* or *what* performs a task		Roles of teacher & students; interaction w/outside world
Operational; *how* a task gets done		Specifications for activities, participation structures, and tool use.
Control flow; *when* tasks are done Organizational; *who* or *what* performs a task		Organization of participant structures; online and offline access to people through collaborative tools/structures

Basic templates for macro-workflows. There are simple rules that determine the basic shapes of workflows – if they branch and if they contain sub-workflows. Building a representation of a workflow involved answering two questions: 1) Did the lesson include any combination[7] or conditional tasks; and 2) Are there performance tasks (e.g., analyze an argument, develop a lesson, collaborate to solve a problem, etc.) in the lesson with multiple related parts (or sub-tasks)? Based on the possible combinations of answers to these two questions, four kinds of basic workflow representations are possible. Examples of their structures are shown in Table 8.

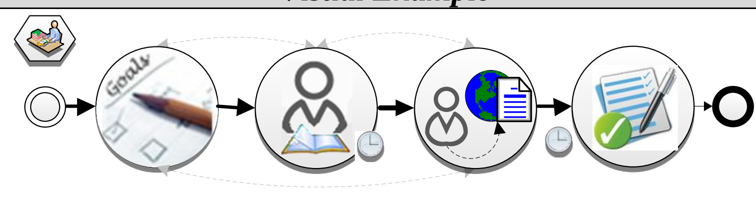
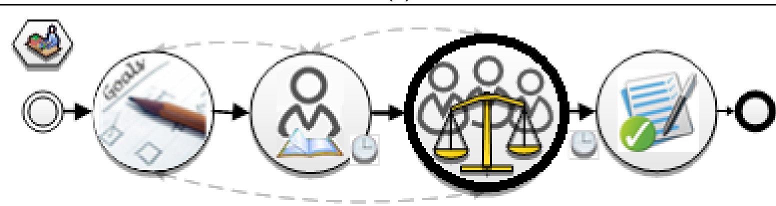
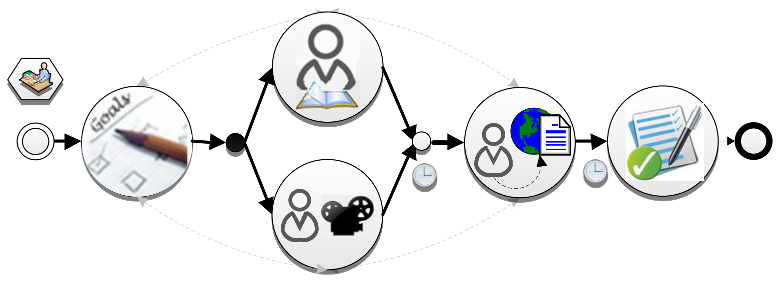
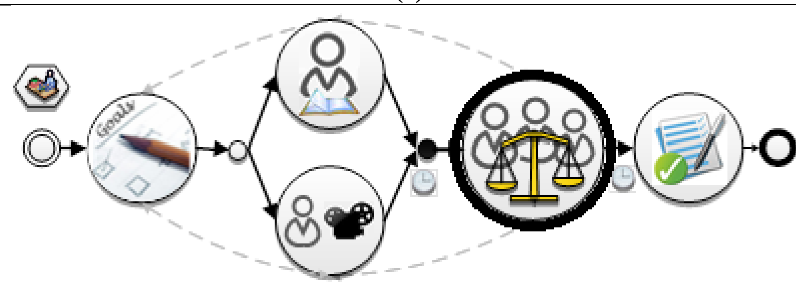
8(a) and 8(b) show lesson that do not include combination or conditional tasks, therefore the workflow representations are linear. In 8(a) the lesson does not include a multi-step performance task and therefore all the icons are the same size (indicating a series of tasks completed individually). In 8(b) students participated in a small group analysis task after reading. Analysis tasks usually have instructions, additional resources, and interactions with others and are expanded in a new layer of information represented by a *sub-workflow* visualization (discussed later).

If a lesson *does* include combination or conditional tasks, as in 8(c) and 8(d), then control task icons – open or closed circles – are used to create branches and merges to show and (visually) explain the arrangement of tasks. In 8(c) a student was required to read the textbook and watch a video before writing a report. The closed dot before the two tasks indicates s/he has to do both tasks, but the open dot after the tasks indicates that the student may continue in the workflow before finishing both tasks. In 8(d) the open dot prior to the tasks indicates a conditional branch; the student chooses only one task to complete. However, the closed dot

[7] In the mathematical definition; a *combination* is a subset of items chosen from a set, where the order of the selection doesn't matter. In workflow parlance, a combination would be a subset of tasks to be done in which the order they are done doesn't matter.

following the tasks indicates that s/he must complete the task before going on to the discussion task.

***Table 8*. Examples of potential structures of macro-workflow representations based on the nature of the lesson and tasks.**

Types of Tasks	*Type of workflow*	*Visual Example*
combination/ conditional tasks No performance tasks w/sub-tasks No	Linear; no sub-workflow	 (a)
combination/ conditional tasks No performance tasks w/sub-tasks Yes	Linear; w/sub-workflow (accessed by clicking bold circle)	 (b)
combination/ conditional tasks Yes performance tasks w/sub-tasks No	Combination branch; no sub-workflow	 (c)
combination/ conditional tasks Yes performance tasks w/sub-tasks Yes	Conditional branch; w/sub-workflow	 (d)

In reality, especially in online learning environments, it is not always possible to control where a student begins a lesson, what order s/he will do tasks, or how many times s/he will re-visit a task before completing it. So along with solid lines that indicate the *intended* flow of a lesson, I included dashed lines to show that students may start a lesson in an unintended place and take an unintended (but still productive) path to completion.

Attributing information or data[8] to a task. The examples in Table 8 show only tasks and their order. When I added the functionality to interact with a representation and retrieve hidden (i.e. layered and separated) information or data it was elevated to the status of workflow visualization *system*.

Each element in a workflow visualization system has some type of information or data attributed to it which is displayed in a standard html tooltip or a smart tooltip (Figure 17).

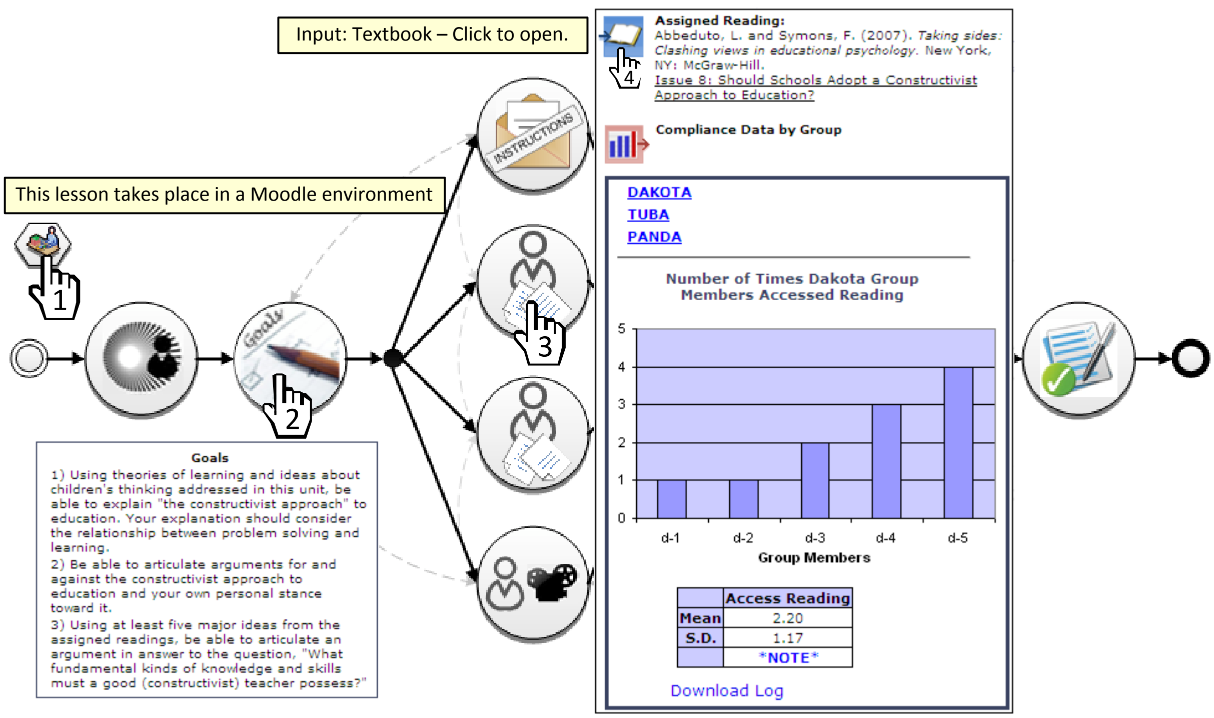


Figure 17. **Examples of tooltip displays.**

Placing the cursor tip in:

1. the 'workspace' icon causes a standard tooltip message to appear.
2. the 'goals' icon causes a smart tooltip that displays text to open..

---

[8] I make the distinction that *information* tells the viewer about the task whereas *data* is generated when students do the task.

3. a ‘student reads document’ task icon opens a smart tooltip that displays information and a link to an assigned reading and graphically displayed compliance data. Input and output icons are displayed in the smart tooltip and hyperlinks to three groups are listed within the compliance data box. There is also a link to download the activity log.
4. the ‘input: textbook’ icon causes a standard tooltip message to appear.

I used new windows that display in front of the web browser window to separate and layer information, most obviously in sub-workflows and micro-workflows.

Sub-workflows. I noted previously that some tasks include multiple related sub-tasks. To analogize with a bit of network terminology, a *parent-task* has subordinate *child-tasks*. For example, the expanded ‘Early Brain Development’ lesson shown in Figure 15 includes a presentation task in which each group is asked to explain how the development of language and mathematical reasoning are intertwined. The parent-task is the presentation of an explanation, which contains three child-tasks – recall concepts from a prior lesson, watch a video, and discuss as a group. The relation of the child-tasks within the parent-task is described with a *sub-workflow*.

A sub-workflow is similar in appearance to a macro-workflow; the major differences are that a sub-workflow representation opens with a general description of the task, and doesn’t include start, stop or workspace icons. On a web page a sub-workflow image is not just a representation; it is also a navigation tool. When the cursor tip is moved over individual icons the information display in the window below the representation changes to displays information or data related exclusively to that task. In Figure 15 - SUB-WORKFLOW LEVEL, the information displayed is related to the group discussion task. Some sub-workflow tasks (like the one shown) have multiple pieces of information or data associated with them and these different pieces are organized and differentiated by a row of input and output icons in the header of the display window. These icons also serve as a kind of navigation bar; moving the cursor over each icon displays a certain kind of information in the display window. In Figure 15 the four icons in the header represent the discussion question (an input) followed by three output icons: one for compliance data, one that allows the user to download transcripts of each groups discussion, and one that provides a link to the micro-workflow of the analysis task.

Micro-workflows. A micro-workflow is a special case of data attributed to a sub-workflow element – usually a discussion task in my prototypes (Figure 15 - MICRO-WORKFLOW LEVEL). Although one of the last levels of data in a workflow visualization, it is also one of the most revealing because it shows when and how often individual students access resources as they engage in lesson tasks, and how they interacted with one another during the course of a lesson. The procedure for building a micro-workflow was documented when I described the first design phase. However, micro-workflow visualizations are interactive and display information about when resources were accessed, when discussion posts were made, and the content of the post. A symbol legend tells the referential meaning of each icon in the workflow. When the cursor tip is placed over resource icons – a video icon or document icon in this case - information is displayed in a tooltip that is associated with that particular icon.

Accessing hidden data. Lastly, I had to decide how layers of information would be revealed as a viewer navigated the workflow visualization. For example, information boxes could pop up instantly on a mouse-over or a mouse click could be required to reveal hidden information. A box could also close immediately when the cursor is moved off an icon, or it could remain open until a “close box” icon is clicked. A box could be a fixed size anchored to a particular spot, or it could be movable, collapsible, or resizable.

Various combinations of all of these options were used in the prototypes. As a general rule of thumb I used mouse-over activation to display information or data about tasks assigned to individuals (i.e., read an article, view a video, etc.), and static boxes activated by a mouse click to display sub-workflows, micro-workflows, or information about the workflow (e.g., the legend of icons) or workspace.

Evaluation of the WVS

Overview. In design phases just described, I received extensive feedback from HAL Online research team members as I presented my work at meetings. This feedback related to the tool and its functionality; for example, team members suggested the need for a student-level workflow and the redesign that showed pedagogical processes in the first phase and called for a workflow legend, separate unit timeline, additions to the lexicon, and an explicit assessment representation during the second design phase. But the feedback was related to the WVS's efficacy to visually represent lessons in *one* course – actually *one unit* of one course. In the evaluation phase of the study I first showed the HAL Online-contextualized workflow visualizations I had constructed to selected groups of Rutgers VMC project personnel, and then asked questions during a following workflow-building task and/or interview to try and determine; if the collection of icons was general enough and the design rules specified enough that they could use them to create intermediate representations of *their* designed learning interventions; and what additional information or functionality needed to be added or enhanced in order to increase the chances they would use the system for analysis and sharing of their interventions?

In my review of the cases from which this data is drawn, I privileged certain things:

- Explicit statements that people made in which they expressed suggestions, caveats, objections, alternatives, limitations, or novel applications.
- Exploratory talk, i.e., how they used terminology or concepts (e.g., tasks, inputs, outputs, flow, or sub-workflow) of the WVS to talk about their own courses or practice.
- Instances of interpretation of an activity depicted in a prototype visualization; e.g., a comment made about how students were engaging in a task in a specific prototype lesson based on the viewer's "reading" of a visualization.

Three of the cases I report on here, consisting of a mix of presentations, a workflow-building task, and interviews, contributed to the evaluation of the WVS. In addition I will report on a case that is an aggregation of two meetings; one with a former IBM systems analyst and the other with Rutgers Libraries software developers. To conclude I will share a case of the HAL-O research team attempts to use the prototype visualizations as an evaluation tool.

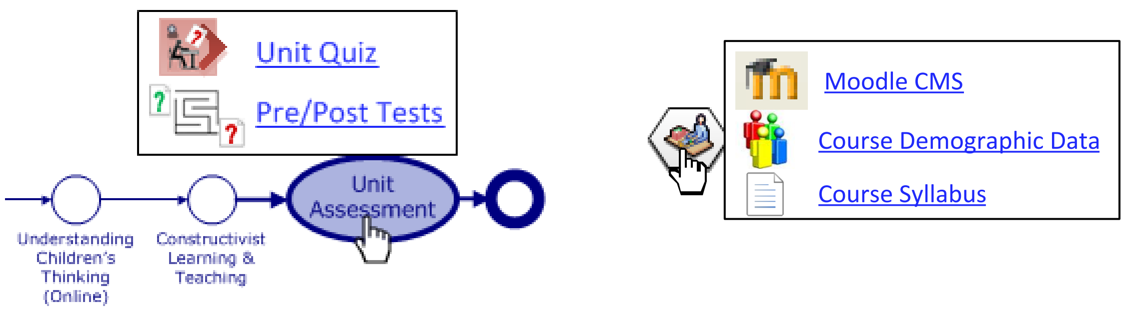
Case #1: Rutgers VMC senior PI's introduce revisions and tensions to the WVS. This case spans three interactions with two Rutgers Senior PI's, both professors at Rutgers University, who will be identified here by their initials, CM and CHS. The interactions took place on two days in late July, 2010 during a VMC PI and evaluator meeting in Madison, WI. On the first day CM and CHS viewed my presentation along with members of the HAL-O design team and the VMC project evaluator. This was the first opportunity for them to see and hear an explanation of the web-based workflow visualizations. Two days later they completed a workflow-building task followed by an interview (both described in Appendix B).

As noted in Table 3, CM is the director of Robert B. Davis Institute for Learning at Rutgers. Her longitudinal study of the development of children's mathematical reasoning produced the 22-year corpus of videos used in the VMC project. As part of her research work she and her team have developed interventions for pre-service and in-service teachers to increase their awareness of how children reason about mathematics. At the time of the interview they had developed two strands of TPD for how students reason about fractions and combinatorics problems. These were being implemented by colleagues in several colleges and universities, including Seton Hall, Felician College, and Rutgers University, and as teacher professional development in a number of urban school districts. CM had implemented the strands in her first hybrid/online course that she had taught in spring 2010. At the onset of the VMC project she and her research team were developing and validating an evaluation of the interventions.

CHS's research interests lie in the areas of problem-based learning & computer supported collaborative learning. She plays a less central role in the VMC project; her attention was primarily directed at helping to refine the assessment of the interventions and identifying important metadata to be included in VM records. Her extensive experience working with tools to study in computer-supported collaborative learning, for example CORDTRA, was particularly valuable for judging the relative effectiveness of my WVS visualizations to support analyses.

Initial revisions during the WVS presentation. I used a PowerPoint presentation and project website to contextualize the workflow visualizations and explain how different features of the system contributed to the overall function of an intermediate representation of learning interventions (see Appendix A for slides and screenshots). Other HAL-O members contributed to the presentation. In general participants in the meeting accepted the explanation of the design rationale, occasionally asked clarifying questions - e.g., the meaning of symbols or icons, the representation of intended versus actual workflows, and how data was collected and converted into visualizations. At times the PI's and the project evaluator from SRI (also present) spoke about features of the WVS in terms of their own interventions or research. In particular, CHS noted that a systemic representation of an intervention should also include various kinds of assessment (and demographic) data.

For example, the prototype visualizations do not include pre-post assessment or beliefs survey data that the Rutgers team currently uses in their project course evaluations, but it easily could. The question is where to place it in the visualization? A link to pre-post assessment kinds of data could be placed with the unit assessments (Figure 18a) and the more global data (i.e., demographics or beliefs) could potentially be added to the workspace data (Figure 18b) because it might be relevant for understanding such things as group dynamics and collaborative relationships.



(a) (b)

Figure 18. **(a) Linking pre- and post-test results to the unit assessment. (b) adding a link to demographic data to the workspace icon.**

Tensions arise in the workflow building task. Two days after the presentation CM and CHS were invited to build a workflow representation of one of their interventions using stickers of WVS elements, poster paper, and a marker to draw connectors. I had decided a priori that this method would be more efficient for one trial than teaching them to use and share the adapted version of Microsoft Visio that I had used to build the prototypes. After some discussion they decided to work together to create one representation of an early lesson from CM's online course on the development of children's mathematical thinking. As the facilitator my intention was to intervene as little as possible; I wanted to observe how relative novices would reason about the conceptual tools I had developed to create a visual representation of a lesson. In particular I wondered if they could select and organize generic task icons to show the general structure of an actual lesson they had designed and then contextualize the lesson by attributing specific inputs and/or outputs to each task. Additionally, could they use control flow elements (i.e., start, stop, arrows, branches, and merges) to show the "flow" of the tasks?

It is helpful here to describe the workflow-building task as an activity system (Engström, 1999) with subjects, an object, mediating artifacts, an objective (or outcome), rules, influence of one or more communities, and a division of labor. In this case CM and CHS (subjects) acted on and transformed a sheet of poster paper (object) with stickers, a pen, and some understanding of workflow representation (mediating artifacts) to produce a representation of a specific lesson (objective) that showed both the general structure of and the specific inputs for the lesson. The activity was influenced by theories of pedagogy, workflow, and information visualization developed in respective communities of practice. A division of labor occurred physically between participants and also as they took different perspectives (e.g., facilitator or evaluator of the lesson) during the design process. Finally there were the rules that CM and CHS were to employ that I had developed explicitly for building a workflow representation.

Examining the workflow building task from an activity theory (AT) perspective was productive because it allowed me to look for internal contradictions or *tensions* among the components of the activity system (Engström, 1993). As Collins, Shukla, and Redmiles (2002) note, "activity system tensions provide rich insights into system dynamics and opportunities for the evolution of the system." By that logic the discovery of tensions in the system seems key to explanation building (Yin, 2003) because it facilitates isolation of specific initial theoretical propositions on which the WVS was built which can then be revised and re-examined in subsequent iterative evaluations. As it turned out, several tensions surfaced as CM and CHS created a single lesson workflow representation. Tensions were found between a business/applied science perspective of organizing processes versus practices that might be considered norms of lesson design in the education community, and also *within* the process of building a workflow related to educating students.

The two senior PI's had little trouble adapting to the semantics of the WVS during an initial "messing about" process. They were able to decode icons and symbols relatively easily and make analogies between the lexicon categories and their terms for lesson elements – e.g., a reading was an *input*, a question produced an *output,* and *tasks* were what students are asked to do. Putting generic lesson tasks icons together in a prescribed order and attributing inputs and outputs to each task proved to be less intuitive, at least for CM. For example, she suggested that they start the workflow with a reading assignment, but there was confusion as to how to place an icon in the workflow.

> CHS: Okay, this is a start icon. Then now we need something with a…
> CM: Then we need an input icon; here's an 'input: document'.
> CHS: Yeah, but that's not our…we have to have a task before we have a…
> CM: The task could be a reading, but that would be for everybody.

Like many instructors, when CM looked at her lesson she saw it in terms of the specific things she asked students to do – i.e., read *this* specific article (chosen, perhaps, from a portfolio of similar articles) and do *this* specific problem. While her lesson had an underlying structure that could be described in a generalized way (one that she may use repeatedly and other instructors may recognize or use themselves) it was not explicit in the way she talked about or initially tried to create a representation of the lesson. What she initially suggested to be represented in the workflow was not the generalized task icon for reading, but a visual symbol of a document to be read (Figure 19a). In the dialog above CHS seemed more attuned to the idea that the reading would be represented on a general level with a task icon and at a lesson-specific level by an input icon and a description of the assigned reading (Figure 19b). In the last statement by CM above, she seems to acknowledge and reject the task→attribute order of creating the workflow representation as if to say her objective is not to create a general lesson structure for anyone to use but rather a representation of a lesson that is specific to her course.

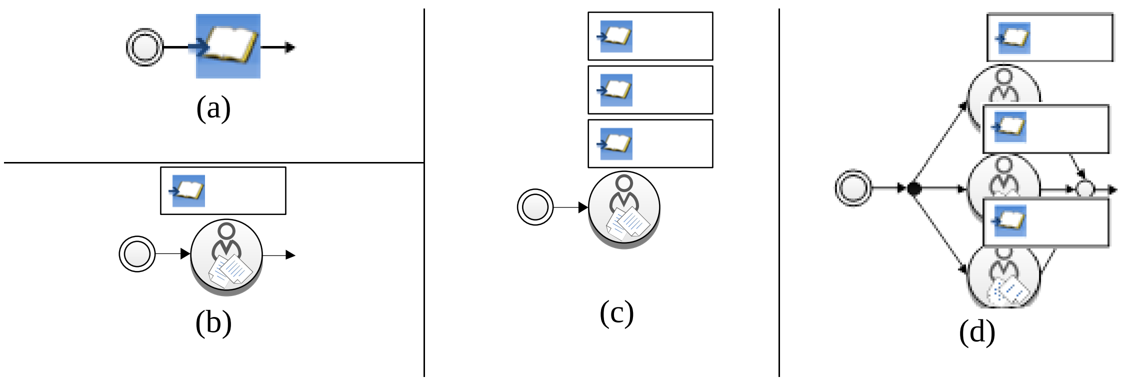


Figure 19. **(a) Incorrect representation of assigned reading; (b) correct representation. (c) Incorrect representation of three assigned readings; (d) correct representation.**

This short exchange between the two senior PI's reveals a tension between a primary purpose of workflows (i.e., identifying and ordering elements of a *process* at a sufficiently general level to facilitate adapted reuse) and a primary purpose of lesson design (i.e., identifying and ordering specific resources and tasks that student will use to accomplish specific learning goals.) In retrospect, it seems unrealistic to try to synthesize ideas from diverse communities of practice and expect there to *not* be tensions.

This is not to say the two are incompatible; it is certainly possible that an adaptable general lesson structure can be induced from an examination of several designed lessons. For example, an instructor may notice that her lessons follow a pattern where students examine a solution to a prototype problem, then read (or view a video) about the problem, are asked to work collaboratively to solve more complex examples of the problem, and finally asked to reflect on the solutions to produce general principles. This pattern can be generalized as a workflow into which the teacher can insert various resources and tasks.

My rules for building a workflow representation had the senior PIs first identify and order the general tasks of their lesson, and then attribute resources (i.e., readings, video, or problem to solve) to each task. But as the dialog above shows, it was more intuitive for CM to reverse the process; list the resources that she had in mind for students to use and then assign these to generalized tasks.

In retrospect this seems like a more natural progression for an educator/lesson designer because a general structure would have a better chance to emerge from the particulars of a lesson that s/he already has in mind than it would from a visualization of abstract elements in space. Over time and with practice, I would expect general lesson structures to become more immediately recognizable to the lesson designer.

This tension, then, could be resolved or diminished by modifying the rules for assembling WVS workflow visualizations so that designers would first list resources and then attribute them to general descriptions of tasks (i.e., read document or view video).

While CM and CHS quickly accepted the logic of the task/resource representation as shown in Figure 19(b), both PI's reasoned incorrectly about how to represent multiple readings, as shown in this exchange:

> CM: What if there were multiple documents? Now we ask them to read…they have to read three articles. Do we put three of them in when they have to read three? We have to put three of them in somewhere.
>
> AJH: So you'll want a task icon for each document that they read.

CM: No there's…no. There's all these readings and then one task.
CHS: There's one task; I'm putting the inputs to one task 'cause they're happening together (Figure 20c).

Both seem to reason that the *act* of reading is one task regardless of how many different articles are read. However, in my WVS representation there would be three reading tasks, each with its own input (Figure 19d) because students are assigned three separate readings.

This exchange illustrates a fundamental tension when developing any workflow: one of granularity, or abstraction. What constitutes a "task?" Workflow logic is based on a computer *information-processing* metaphor where one piece of information is processed in one clock cycle[9]. By this logic the life span of a "task" is as long as it takes to process a single piece information. CM identifies three separate articles in the dialog above, therefore students are asked to "process" three pieces of information (i.e., inputs). They do this one at a time as three distinct reading tasks (as represented in Figure 19d.)

The issue of task granularity/abstraction leads to another tension that exists between the representation of a workflow and the actual implementation of *some kinds* of lessons. Ordering of tasks is a core characteristic of a workflow representation, but how do you represent the order of tasks in a lesson when the order that the students access the resources/tasks doesn't matter? The PI's grappled with this question in the dialog below as they discussed how to arrange the lesson tasks in their representation:

CM: We were talking about Sandy and Benny and contrasting them.
CHS: Now is this before or after they've done the problem-solving task?
CM: Well, everything's posted at the same time and the order – he talked about this – the order doesn't matter.
CHS: But I think the order *does*…
CM: It didn't matter for this piece of the course. These were all posted the same time.

[9] While many processes occur simultaneously in a clock cycle, each process is a separate distinct task.

CM referred to the way that lesson resources and information was displayed and made available on her online course management system (CMS) when she argued that students could access any of the task resources at any time and in any order. She also argued that she wanted a constructivist-oriented lesson design where she as the instructor doesn't predetermine students' behavior. She wanted the freedom to be able to react to and guide the formation of ideas that evolved from the students' problem solutions and discussion posts. While her point about the CMS was true and her choice of pedagogical strategy was legitimate, I asked if, when CM designed the lesson, a logical order of tasks emerged?

> CM: They couldn't really talk about any of these unless they've read the articles and done the problem. So I would say in the sequence we're telling people, you give them the readings…I don't really care when they give them the problem…and then you have them discuss; you have them think about these questions and you have them post certain responses…

However, she was not willing to concede her point that tasks in a lesson may be done in a different order than presented, or not done at all. This reveals a more overt tension between the rules for workflow processes executed in business and science environments versus the potential workflow executed by a student engaged in an educational intervention, especially in "student-centered" or "constructivist-oriented" interventions.

A typical business or applied science-oriented workflow is well defined to accomplish a certain function and, although it may branch to different sub-processes when executed, it does not deviate from or revisit the programmed sequences of tasks. But students *do just that* when they engage in a learning intervention, especially online:

> CM: [W]hen they [students] start doing these things they'll say things like, "I need more time; I need to get this straight. I need more time before I can respond to these questions."…Now, are they doing the analysis before they join their group? You know, of course they are; they're doing their own separate individual analysis. Now they're ready to make their ideas public. They've thought about it; the video, the task, and the questions…and often

> the readings, they go back into the readings. So now the conversation…you can start to see flow.

A student's individual workflow may begin at the concluding activity where s/he previews the main activity of the lesson and uses it as an advanced organizer to focus her/his reading, and then go back and forth in no particular order between resources and performance tasks. CM notes elsewhere in the interview that in education we introduce ideas that are novel to students who aren't experts; they develop expertise by revisiting ideas or exploring related exemplars, each time bringing a little more understanding of the idea with them. This behavior is very much at odds with the linear notion of performing a sequence of tasks in a fixed order, even iteratively, as is usually done to complete a business or scientific process.

It is difficult (or impossible) to visualize how we would show in an *a priori* workflow representation that we *intend* or *expect* this random non-sequential behavior from students; hence CM's reluctance to commit wholly to a fixed lesson structure. In the WVS design I used dashed lines in the lesson-level workflow to indicate optional paths that students might take. However, since the lines connect virtually all possible paths a student might take, they don't actually provide much additional insight about the workflow of any given student. This notion in itself – that each student who engages in a designed lesson can start from a unique spot in a prescribed sequence of tasks and create her/his own workflow of an undetermined direction or number of tasks – does not fit with another core characteristic of workflow technology; that the sequence in which tasks are performed is controlled by the order they are represented in the workflow representation. This doesn't mean that they can't be diagrammed; it just means they can only be diagrammed a priori as an *intended* or *suggested* representation of a lesson workflow. But such an *intended* workflow serves a valuable function by constraining the students' workspaces. If we cannot anticipate their workflow, we at least know what resources they will be using and to a large degree what they will be attempting to do with them. In online environments we can recover data about their interactions with those resources and the tasks they do and use it to construct individual workflow representations for each student – the *actual* lesson workflows. We can also group these individual workflows to see and trace interactions of group members during collaborative tasks. This is, in fact the retrospective function of the WVS *micro-workflows.*

Additional tensions and revisions revealed in the interview. After completing the workflow building simulation CM and CHS answered a series of semi-structured interview questions targeted broadly at four aspects of the WVS (see Appendix B) but more specifically about the user interface and potential of the tool to be used to support design and research. The prototype workflows were projected on a screen and referenced during the interview.

Almost immediately the two senior PI's shared an observation about a limitation that turned out to be a fairly significant tension for all potential users in the structure of the WVS:

> CHS: I think there are pieces, like of social infrastructure that it won't capture in terms of…you know, how constructivist is a teacher?
>
> CM: What bothers me a little bit about it…it just occurs to me as you're saying this…that we don't know *how* the video is being used…We know they *used* the videos, but we don't know *how* they used them. How would you find that out?..you'd have to get other data. I don't think this does it.

In the parlance of the Workflow Management Coalition (Hollingsworth, 1995), CM essentially said that she was able to retrieve *functional* data from the visualization - what was being done – but not *operational* data that describes the rationale for including a resource or how something is intended to be used or done, or how it is *actually* used or done. This echoed a criticism of the WVS made by SD in the pilot study that did not get addressed in the prototype version used in the case studies.

On one hand it would have been as easy to add this operational information to the workflow visualization in the same way that I added lesson goals or links to resources; by hard-coding it into each html file. But this information was not as convenient to recover because it was not entered into the Moodle course database. To recover the necessary information I would have had to interview SD, the designer of the prototype lessons, about each resource and task and I simply decided to forego that process and push into the next design cycle the development of a mechanism to capture and display this information. The efficient way to capture design rationale or post-instruction reflections would be to make available a form into which the designer could enter relevant information as s/he adds tasks and resources to the intended workflow visualization. To use forms, the WVS would need to be connected to an SQL database, and that technology was not available for this design cycle.

In general the senior PIs had little or no trouble decoding the icons and were generally satisfied with the lexicon, although CM's initial reaction was that they were designed for a specific course and implied that they were perhaps too specific. However as we reviewed *every* task, input, and output icon her opinion softened and she made a handful of suggestions to revise the descriptions of some to make them more general and thereby more broadly usable. For one task icon in particular - "student reads goals" - her analysis suggested a deeper tension with the rules for WVS design.

> CM: Student reads goals for the lesson. Well how do you know he reads the goals? …*asked* to read goals. Students are *presented* with goals for the lesson, you know, something like that. You're "reads"…you're kind of implying [a] behavioral thing that happened; you don't really know.

This particular comment goes beyond semantics; it's a categorization issue. Some elements represented in the workflow visualizations are key elements of lesson design in general. For example, the first steps in "backward design" of a lesson (Wiggins & McTighe, 2001) are to establish the goals for the lesson and decide how those goals will be assessed. I categorized reading the goals or the assessments (or instructions or focus items) as a lesson *task* represented with a circular icon, but CM's observation suggests that this is a miscategorization of lesson *elements* that are essential for establishing the parameters of the workspace. This in turn suggests a modification to the representation of these elements as hexagons rather than circles (because I chose the hexagon[10] to represent elements related to the workspace). In addition, these lesson elements have input (e.g., focus, goals, and instructions) or output (e.g., assessment) characteristics, so their respective icons can be color-coded blue or red. This re-categorization, illustrated in Figure 20, would increase the efficiency of visually processing the workflow representation.

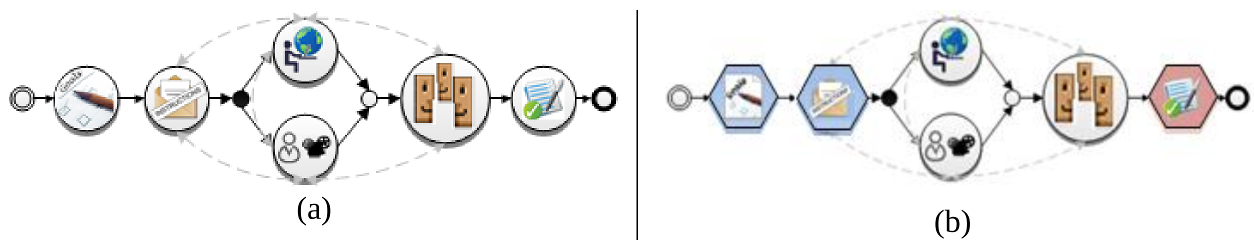


Figure 20. **Workflow with lesson elements represented as (a) tasks and (b) as workspace elements.**

A final significant tension related to division of labor arose when I finished the interview with a question about the next steps to develop the WVS:

> CM: I was just thinking in the back of my head, suppose we want to capture the workflow so…these other people who are doing these interventions could study [them]. Who would build this? Would you build it for them from what we've learned about them? 'Cause I don't think you'd get them to do it.

CHS offered a similar observation that the WVS process of building workflows has to be operationalized into a tool that educators and lesson designers can easily use. Both senior PI's favored the idea of a tool that would allow them to select representative icons from a library,

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[10] As a general flowchart icon a hexagon represents a preparation stage or initial conditions.

drag and place them in a workspace and place them in a way that showed the intended flow of a lesson, and then annotate them with information such as instructions, resources to be used, or rationale for the task/resource. In a later case study with software developers I will elaborate on this idea for a tool; here I want to say that there are plusses and minuses with such a tool.

A major plus is that a drag-and-drop tool would have functionality similar to programs that designers have likely used, i.e., Microsoft PowerPoint or draw programs. Both CM and CHS volunteered that if a goal was to quickly and easily *share or compare* lessons the tool would facilitate that. For people who use graphic organizers (i.e., flow charts or concept maps) to organize or understand the relationships between ideas a drag-and-drop tool would be ideal. But when asked if she would use the WVS for lesson *design* CM responded, “No, because I don’t think of it that way.” So that is a minus; it may not align with the way lesson designers think about design.

Another strong consideration for a tool would be its ability to supplant or leverage the design work that educators are already performing. For example, CM is already entering information into a CMS (i.e., eCollege) for her online course. Would she be willing to enter all of that information again into an *additional* system in order to create a workflow visualization of the course? It should be no surprise that her answer was no, or that CHS doubted that many instructors would have the time to do so. A better tool would “mine” the information that CM entered into eCollege as she created a lesson structure, and then automatically generate a workflow visualization. This might require that she answer a few additional questions about the tasks and resources she uses in her lesson, but that would be significantly less time-consuming than re-entering all the information in a new system. Additionally the same workflow technology could be applied to mine student-generated data as they engaged in a lesson and automatically generate individual micro-workflows. While a tool with drag-and-drop functionality would be useful for making “sketches” of lesson workflows to share with others, using workflow mining techniques and applying a few design rules to that data would leverage work that instructors were already doing to automate the process of generating workflow visualizations.

Summary. From my interactions with the senior PIs across a presentation, a workflow-building exercise, and an interview, a number of tensions related to the design and potential use of the WVS were revealed. Some were relatively minor and can be resolved with correspondingly minor actions; adding links to data (i.e., demographic or research data), changing the sequence of steps for building workflows, or changing the shape/coloration of icons. Some are resolvable with a little explanation, instruction, or practice (e.g., the grain size of a task, or ordering elements in a “constructivist-oriented” lesson). And finally, some of the tensions require major design work to resolve. First, there is the lack of ability to annotate elements of the workflow. If the overarching goal of the WVS is to create intermediate representations of learning interventions that facilitate sharing and design-based research, then providing metadata about the rationale, implementation, and outcomes of the lesson seems essential. The technology to collect and display this information is readily available and, although adding it constitutes a major design upgrade, it is fairly routine work to add the functionality. Perhaps the most significant tension revealed by this case study is one that has less to do with synthesizing theoretical propositions from epistemologically different domains than from the prosaic reality of convincing potential users to use the tool. The prognosis from both senior PIs was not entirely discouraging, but realistic; in a nutshell, educators are already too busy to invest extra time to learn or use a tool that creates data that they also don’t have the time to analyze. The latter concern is addressed by; (a) the design of information displays that take advantage of human visual processing power to quickly detect patterns and interest points in a visualization, and (b) layering and separating of data combined with navigation tools to access data on demand that facilitate deeper analyses. The challenge of time may be addressed by tightly integrating the WVS with the designer/educator's CMS in a way that the WVS would mine the information and data that instructors (and students) create anyway when they build or engage in a course. I briefly discussed this idea earlier and will elaborate on the challenges of integrating the WVS with a CMS later in this paper.

Case #2: Rutgers VMC Project Managers. MP and RS play key instructional support roles in the VMC and for ongoing research and teacher professional development (TPD) related to children's' mathematical reasoning at Rutgers University. MP is the Research Project Manager at the Robert B. Davis Institute for Learning and a Co-PI of the VMC project so has been very involved all facets of Rutgers work on the project. This includes design and application of data gathering instruments used in instructional settings, data analysis, complete management of field studies (i.e., scheduling, distribution of intervention materials, and collection of data) and has been a co-instructor of their recently added online course on children's mathematical reasoning. RS is a Senior Researcher who provides technical support in the form of video production, application programming, and maintenance of the eCollege online course (in which he was a student). He has also spent a great deal of time in the field as a videographer and processes nearly all of the collected data for both quantitative and qualitative analyses. Both MP and RS exhibited a good conceptual understanding of the technical side of instructional design and of research of instructional environments. Both had spent a substantial amount of time previewing the prototype workflow visualizations before the meeting; they knew basically how to navigate across and within them, and acknowledged the technical sophistication of the prototypes. Because of this and the fact that both were relatively inexperienced in the area of lesson design, I decided to forego the workflow-building exercise. This in turn contributed to longer and more detailed speculative discussions of technical aspects of data capture, organization and presentation during the presentation and interview.

For this case study MP and RS are combined into a single *subject* that I will call “Project Manager.” I am confident that their comments can be aggregated into a single perspective because their roles and experiences in the project overlapped in many ways; RS was a researcher as well as a videographer, and MP occasionally ran the camera or edited video or other data. The Project Manager, then, is the *subject* in an activity system with the *objective* or *goal* of providing project instructors with the resources and basic curriculum that they need to implement project interventions across a range of settings (i.e., mathematics and math education courses, graduate courses, and inservice seminars.) The Project Manager acts on these instructors/courses (*objects*) using a variety of *tools* (i.e., meetings, emails, project website or CMS, and CD/DVDs) and the system is regulated by *rules* (e.g., instructors are autonomous with respect to how they implement the materials), the norms of the *community* itself, and a *division of labor* (which includes multiple instructors and within the Project Manager position itself.) A concurrent *objective* for the Project Manager is to collect data to be used in analysis of how well the system is meeting its instructional objective and a variety of tools are employed with the instructors and within the courses to meet this objective. These include pre-post assessments, belief assessments, and interviews. MP and RS critiqued the WVS with respect to its potential as a tool to aid in the management and assessment of the Rutgers VMC project and identified several tensions. Some they identified within the WVS and others were expressed in terms of implementing it with their online course and with instructors across their project. In addition they identified some current tensions in their work that they thought the WVS might resolve.

How interpretation affects the ordering of tasks in a workflow. Two issues were prominent in our conversation during my presentation of the WVS. The first concerned the potential effect of differing interpretations by instructors/designers of the relation of lesson elements on the appearance of workflow visualizations; would that cause visualizations that should be identical to be represented differently, and would *that* be problematic? MP made an interesting observation about the structure of the workflow visualization for the "Brain Basics" lesson:

> MP: …just a question about a workflow representation. Okay, there were two things that were assigned for reading, but given that one is an introduction and one is the next chapter – that basically that they are sequential chapters in a book, it's interesting that the workflow representation shows a split as opposed to having them in order…I mean, I suppose someone could read chapter one and then the introduction, but…

First it was noteworthy that MP raised this question from her examination of a workflow visualization that contained a parallel branch. With no tutoring from me she was able use the system and resources within the workflow website to; (a) interpret the "split" as meaning the order of the readings didn't matter, (b) discover exactly what the assigned readings were, and (c) make a judgment about the structure of the lesson *from the lesson visualization*. This was an example of a workflow visualization doing what it's intended to do: organize information and display it in a way that gives people access to quickly see potential patterns or interesting phenomena[11].

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[11] MP does this again later in the presentation with still pictures of a classroom activity – "I noticed there were very few Unifix cubes for the number of people at the table" – which she turned into an analysis of how students are engaged in the lesson and the potential effect that might have on their learning.

MPs observation revealed a tension related to the correct interpretation of the design rules for the display of workflow visualizations. I tried to keep them simple but, like many rules, they are open to interpretation. For example, the rule for branching is stated as a question; does the order of the tasks matter? If yes, the tasks are displayed linearly by order; if no, a branch is inserted and the tasks get stacked according to the designer's preference. As MP's observation illustrates however, it might be open to interpretation whether the answer is yes or no. This in turn suggests that there would be a difference between a representation of this lesson designed by MP and mine that would be immediately obvious to a viewer.

MP's observation reveals a design tension that is not a product of the WVS but is inherent in the act of designing a lesson in all environments: What is the best way to introduce multiple resources and tasks to help students learn more deeply and efficiently? Sometimes the answer is obvious but other times it is not. When it's not it seems reasonable to say that the configuration of a lesson will differ between designers. The rules for building WVS workflow representations *should* capture and display designers' different interpretations because that's what allows us to compare different instantiations of lessons with the same goals and possibly the same resources, including assessments. Given MP's reaction to my design, the WVS shows potential to be sensitive to those differences.

Can the WVS collect data about what actually happens in a classroom? The second tension MP and RS expressed was related to adapting the WVS to face-to-face environments where "mining" of workflow data would be less automatic. They shared the concern raised by CM in the previous case study of how to represent what actually happened during the implementation of a lesson. Like CM, they privileged flexibility for field teachers to implement VMC video-supported lessons in any way that they saw fit, and understood that this would result in several different workflow representations of lessons that used essentially the same resources. And like CM they wondered how the data was going to get collected, although they were certain that *they* would manage this process in their particular research environment.

Accepting that, they were concerned about how processes of data collection could be automated within the WVS so that the system would display each individual teacher's intended workflow for her class, and capture and display what actually happened in the lesson as faithfully as if they (MP and RS) were there taking field notes and capturing video.

They acknowledged first of all the need for a tool to create workflow visualizations that was simple for their field teachers (or field researchers) to use and that did most of the work transparently as they designed or implemented the lesson.

> MP: Conceptually the desirable thing would be, have a tool that takes it as you lay out these things where you want them on a computer workspace; that it generates the code by your activities of actually laying out and arranging where you want them.

The next step they suggested was the ability to annotate the workflow using web-based forms that the field teacher or researcher accessed via the workflow.

> RS: I think it's possible to make something that would, when you hover over it and click it brings up all that information. Like they have a form that they fill out...

His idea was that teachers might open a version of the workflow that allows them to double-click on any icon and have a dialog box open where they could write a note about how the task or lesson went, or complete a checklist, or upload data from different sources (i.e., images from a digital camera or text from a cell phone). The details of these ideas were discussed in the previous case study so I will not reiterate them here. But I will add here that from their field experiences MP and RS elaborated these basic ideas with suggestions (and speculation about the technical challenges) for evolving the WVS into a more interactive tool. These included adding a simple drawing tool that would allow field teachers to quickly make digital sketches of things like group seating arrangements, and adding the functionality for instructors to change a workflow visualization by adding or removing task/resource icons. This last suggestion is significant and is discussed in the next section.

Should we include the "unknowable" in a workflow representation? In the course of the interview MP raised a tension that was both subtle and significant. In essence her question was, should or *can* we represent a task that *might* be generated by students during the course of a lesson in a workflow visualization of the lesson? The consequence, of course, is that the visualization will either fail to correctly depict the actual lesson (if it is added but not executed), or fail to capture and document design changes in the lesson (if it is not added but occurs). The consequence is significant with respect to design-based research if the WVS is expected to provide robust documentation of *all* design changes over the course of an experiment. In their exploration of this question MP and RS supply several insights that point toward a way to alleviate this tension.

As context for answering my interview questions MP used the online course they had completed in Spring, 2010[12]. MP was a co-instructor (with CM) and RS was a student in the course (and the technical designer). This was a graduate-level course with a mixed population of teachers of mathematics, K-12 instructional leaders, and future teacher educators. The focus of the course was for participants to gain a useable understanding of how children's mathematical reasoning about targeted mathematical concepts develops and evolves as they grow. In reflection on the structure of the course, MP and RS seemed to hold slightly divergent views. They agreed that there were three phases to the course – introduction of general theory and principles, the problem-solving intervention, and a final group project - and that the workflow visualization

[12] In actuality the course had a hybrid design that included face-to-face meetings.

principles of the WVS applied to the second phase. From there however their viewpoints differed. From a student's perspective RS saw a stable lesson structure that repeated from week to week:

> RS: [I]t kind of went, work on this problem on your own, watch these videos of students working on the problem, read some articles related to the problem, real-world applications, and then discuss in your groups. And then the next week would start with group discussions with the other groups.

He estimated that, as a technical designer he could have probably mapped out all of the activities of the course without a major problem with the icons I had developed, and that the difference in structure between the designed and implemented lesson would be insignificant.

MP, on the other hand, was hesitant to commit to the lexicon without talking through the design considerations and instructional goals of the course. She described a general pedagogical strategy in which students were given a question, a task and tools to do the task, and then she and CM observed the knowledge-building process that emerged in each group and shaped their interactions within or between groups based on those processes. As she reviewed lessons from the course website she concluded that such an order was recurrent in many of their lessons:

> MP: … each one had the same kind of prompt, which again, kind of repeats from the introduction to the unit itself. You know, as you study the videos pay attention to the children's sense-making and arguments, discuss the form of the arguments they made and the evidence they provide and so on.

RS hypothesized that a typical course lesson seemed to have two kinds of workflows with the first having a required and "suggested" parts:

> RS: …so there was, like, *assigned* workflow, which would [be] like "read the assignment, watch the videos, read the articles, post response, discuss in your group." Then there was the *we hope they do this*, which would kind of throw in "work on the problem"…And then there was *what students actually did* workflow…

MP argued that a combination of broadly stated instructional goals, autonomy granted to individuals/groups in the course, and the diversity of experience students brought to the course created a situation where she would not be able to comfortably predict a general workflow representation. To RS's "*we hope they do this*" premise she added qualifiers "*because we want them to…*" and "*but…*" that she was uncertain could be captured by the WVS in a workflow representation. MP illustrated her point with an example about the use of manipulatives. She explained that the design intent was that people should have manipulatives available because it *may* be useful for them to build some of these models, or even to build some alternative models which *might* help them to think critical and reason mathematically about the problem solving tasks in terms of both understanding the mathematics itself and the implications for teaching. But:

> MP: [A]lthough everyone left their first face-to-face meeting with their own set of Cuisenaire rods… it was really up to the participants whether or not and how often they actually took out those rods and thought about the models…

The nature of this course was such that it attracted a significant number of practicing teachers; some that might be teaching the content under consideration, and others who might be familiar with the content but who teach at another level. And the course also enrolls non-teachers of varying levels of mathematical skill. On one hand CM and MP wanted to provide tools that relative novices could use in the same way that children did to practice the mathematical manipulations involved in reasoning toward correct problem solutions. On the other hand, they didn't want to insult the intelligence of the experts in the course by requiring them solve relatively trivial problems. So they didn't require students to use the manipulatives to solve problems, but gave them the option to do so. This doesn't seem to be particularly problematic as long as some kind of problem solving icon is included in the intended workflow. What is significant, though, is the next steps after solving the problem. What they *hoped* their experts would do was contribute their pedagogical knowledge about solving the problem to the course by initiating discussions about the implications for teaching. However:

> MP: [F]rom the instructors' point of view it didn't seem appropriate to ask students to do that until some of them, at least, were spontaneously offering that. Because you don't really know whether or not they're ready to offer something like that until you see some evidence of it.

Going back to the tools available in the WVS for representing a learning intervention and the prototype workflows, MP seemed to be saying that there is no icon or no prototype that represents the complex pedagogical strategy of exploiting some students' knowledge and expertise *if* or *as* it becomes available in the context of some other lesson task. She notes that the students in their online class did do just that, but that it is an implied task– i.e., *we hope students will do this* – that she and CM seemed to *expect* would become part of the workflow, but they were not confident enough to say it would happen or prescriptive enough to force it to happen.

If a lesson designer working with the WVS was in the position that MP just described there would be two possible design outcomes that would potentially result in misrepresentation of the actual lesson:

- Include a "students share expertise" task in the workflow representation and students don't share, or
- don't include a "students share expertise" task and students do share

If either of these scenarios occurs, than the instructor/designer/researcher has to take some sort of action to correct the design record. If tasks can be annotated post hoc (as discussed earlier) then such a mechanism could be employed to note that an expected or hoped for action did not occur in the *actual* workflow. Another possibility is that a toggle function could be added to task icons that would show a negation symbol over the icon when selected (i.e. like a mute indicator for a volume control) to indicate the intended action did not occur.

On the other hand, if the students spontaneously perform an unexpected action, or the instructor infers from some actions that the students are primed for an additional task and spontaneously adds it to the workflow, then this additional activity/task has to be accounted for (i.e., added to) in the workflow representation *post hoc*. Editing functionality would have to be built into the system that would allow an instructor or researcher to easily modify the visual appearance of the workflow, for example by dragging an icon that represents the new task to the spot of the action and pasting it into the workflow with a mouse-click. To preserve the design history of a lesson, each previous workflow visualization would have to be archived and indexed (in the same way wikis are updated and archived) so that researchers could easily trace the documentation of the design experiment.

As an extension that was related but not restricted to this discussion I asked if they would want the ability to create icons if the lexicon did not provide a satisfactory match to a task of resource. MP suggested a placeholder that consisted of the shape for the category of icon (i.e., circle for task or rectangle for resource) and some descriptive text. She proposed that a placeholder icon would be local to the workflow in which it was created. This seems like a nice compromise between a closed library of icons that may be insufficient and a carte blanche icon creation tool.

Leaving too much for granted with the user interface. Both MP and RS expressed this concern about the user interface; they didn't think a user would realize, or would underestimate, how much information was hidden in the visualization if s/he didn't intentionally mouse-over or click on links embedded in the workflow visualization. The implication is that if people don't know to use the mouse to interact with the representation it's not hierarchical information visualization, it's just a picture. This has implications for using the tool to collect information (i.e., instructors won't know that they can annotate the workflow), for research (i.e., analysts won't be aware of explanatory data, especially with respect to qualitative analysis), and for sharing details of an intervention with other educators. They offered four specific suggestions to help resolve this tension:

- Place a message in a textbox beside the workflow that explained how to interact with the image. The textbox could include a close button or a 'Don't show this to me again' checkbox.
- Make a (prominently displayed) link to a tutorial. RS suggested using a screencast that briefly showed how to access the various levels of information.
- Use standard web browser or application features that already have meaning for the user. For example, use standard blue hyperlinks to articles or videos in task popup boxes instead of pictures or icons. Also, use a standard navigation bar (i.e., File, Edit, View. Etc. menus) at the top of the page, or include cues (i.e., downward pointing arrow) that alerted the user that non-standard menus were expandable.
- Make sure that interactions with icons and links are consistent at each level of the visualization.

Inherent project management tensions that the WVS might help reduce or resolve. As a manager of a longitudinal project that is distributed across six to eight diverse sites in any given time, MP is responsible for collecting, indexing, storing and retrieving data that is archived in several forms; e.g., paper, video, compact disc or DVD, or file servers. Reconstructing a representation of a given intervention requires pulling data from file cabinets, shelves, and servers and arranging the various media in a way that shows its organization and implementation and facilitates recall of the outcomes. The procedure must be repeated in order to compare multiple implementations of interventions that use the same resources. A functional WVS would relieve much of the inherent tension that comes with managing intervention artifacts because it would allow her to quickly retrieve records of them from one source. Furthermore, the emphasis on *visual* representations with links to additional information would allow project researchers to quickly see differences in how field teachers were implementing the VMC videos, problems, and readings into their courses – a big improvement over the current system.

Another potential project management challenge is to draw hypotheses about best practices from the data. Ideally design-based researchers want to utilize the expertise of the practitioners who are implementing the interventions to offer suggestions, or support hypotheses that may be suggested by quantitative analysis. But assembling instructors in a timely way and/or supplying them with adequate descriptions of their varied implementations (i.e., that allow them to quickly discover differences in their implementations) is costly and logistically challenging. RS brought up the idea of a community of instructors who would use the workflows to share ideas about lesson design and implementation. He envisioned a kind of blog built within or around the workflows that could be used to focus community members on particular aspects of the implementation and invite them to comment or ask questions.

Summary. The presentation and interview with two VMC project managers revealed tensions within the current design of the WVS that would need to be resolved in order for it to be a useful management and research-supporting tool in their work. In their current roles they are responsible for distributing intervention resources and collecting data about how the VMC interventions are implemented across various settings, which now includes face-to-face and online environments. They see potential for the WVS to shift some of the responsibilities of data collection from themselves as videographers and observers to the instructors. They also see the potential of the WVS for sharing information about lessons through a common repository: MP envisioned quick comparisons of lesson implementations as an early stage of research on their effectiveness while RS suggested the possibility of cohorts using the workflows to facilitate comparison of lesson and an exchange of ideas. None of this will be possible, however, unless there is an easy process (and suite of web-based tools) for instructors to build intended workflows and set them up as repositories of data. In addition to automated processes of data collection, there would have to be a mechanism for instructors or researchers to annotate a workflow both as they built it (e.g., to provide design rationale) or during/after the lesson (e.g., to explain a pedagogical move or reflect on an outcome), and the iterations of design would have to be archived in a way that preserved the design history of the intervention.

Case #3: VMC project instructor. In the case of the senior PIs and their evaluation of the WVS both expressed concern that it would not be sensitive enough to document the tentative pedagogical moves that emerged in the course of a constructivist-based lesson. MP echoed that concern in the previous case study, particularly when it came to the representations of tasks that *might* emerge from student actions while performing a documented task (i.e., a small group discussion). In this case I asked a VMC project instructor to evaluate the efficacy of the WVS to create representations of the lessons she normally offers, which have a more rigid, teacher-directed structure. First I gave her my presentation of the VM and WVS, and then we converted a meticulously documented day-long teacher inservice agenda into a workflow representation distributed across three landscape-oriented sheets of typing paper. During the workflow building exercise and in the semi-scripted interview afterward she shared some pluses and minuses of the WVS.

JL is an experienced teacher educator who works primarily with inservice teachers. She is not affiliated with any university but usually contracts with local school districts to provide professional development (PD) for mathematics and special education teachers. Her PD is grounded in the mathematical strands developed by the Robert B. Davis Institute, specifically with fractions and combinatorics.

In the parlance of Activity Theory, JL is a *subject* that acts upon a cohort of teachers in a TPD inservice configuration (*object*) using resources and a basic pedagogical structure (*mediating tools*) that are aligned with the goal of the Rutgers VMC team to improve teachers understanding of the development of student's mathematical reasoning (*objective*). This activity system is one of the objects acted upon by the project managers as described in the previous study. In that case I examined how the WVS could be used to support functions associated with managing multiple implementations of a designed intervention. In this case I am investigating how an instructor might utilize the WVS for the design, delivery, documentation, and sharing of a lesson.

JL has a great deal of experience teaching from the Robert B. Davis Institute research-based materials; CM was her graduate advisor so almost from their inception JL has been involved in the design and evaluation of the lesson strands she uses. While technically a member of the VMC project, she had little to do with the development of the VM. From my initial presentation she received her most extensive explanation of the searchable video repository that is the heart of the VM and how it would be used to design video-based lessons. She was also introduced to the conceptual model of a workflow building system that she and other teacher educators could potentially use to create visualizations of project lessons.

Over the course of an afternoon at JL's home; (a) I conducted a presentation, (b) we collaborated on a workflow building exercise (that was described in the case of the senior PIs), and (c) I interviewed her about the WVS – her impressions of the user interface and her impressions on how she might utilize it as a teacher educator. MP sat in on the presentation and occasionally offered clarifying or reinforcing comments. JL was an active listener, frequently issuing affirmations such as "Okay", "Sure", and "Um, hmm". She seemed to pick up ideas or adjust her understanding of concepts very quickly. For example, we quickly discovered (with MP's input) that my idea of a task was more global than the mathematical problem-solving focus she and the Rutgers VMC group held. JL quickly grasped the general task→attribute relation that I used in visualizations; more so than CM and CHS had. This may be because she was used to trading activities that were specific to particular lesson strands in and out of a general framework that she used for all her workshops. Finally, she quickly learned the meaning of icons, at least the ones that we were using repeatedly, and anticipated which ones to apply to the workflow representation of her selected lesson.

At the same time JL seemed indifferent, asking few questions or rarely making unprompted comments about the WVS. That could have been due to the fact that, to that point, she had little input into the development of the tool and hadn't given much thought as to how she might employ it. The comments she *did* contribute were meaningful in that they revealed some minor tensions (echoing from a different perspective some that other had raised) but also showed her ease with extracting and reasoning with information from the prototype representations.

For example, JL's daughter was a kinesiology major so her interest was piqued when I mentioned that one of the groups represented in the "Brain Basics" micro-workflow visualization included kinesiology students:

> JL: Okay. Which group is the kinesiology group? I'm curious.
> AJH: The bottom one.
> JL: It is. 'Cause it looks very different than, you know, the others.

She noted that the group was "ahead of the game" because the micro-workflow showed that their online discussions were distributed across the entire week of the lesson as compared to the other groups whose discussions were bunched up just before the due date. Scanning the visualization she also noted (correctly) that in one of the other groups a student had contributed to the group discussion even though s/he had not accessed any of the lesson resources and mused about the quality of that student's contribution. This brief episode showed that JL could interpret the visualizations in the WVS fairly easily to identify potential patterns or interesting phenomena, even though she was a divested observer with only a casual curiosity.

At another point in the presentation, as I showed a digital sketch of the classroom from the prototype face-to-face lesson workflow, she identified valuable information that was missing:

> JL: Got it. Now I'm surprised you don't have who was sitting in which spot at the tables…'cause *that*, to me that's more important than, or *as* important as knowing what the configuration of the (room was.)

This illustrates the point that has been made several times; that teachers (or designers or researchers) need to be able to annotate elements of the workflow visualization during or after the lesson has been implemented because that's when the information becomes available.

Inherent tensions with the in-service format and participants. JL was dubious about her ability to express her lesson elements as a visualization so we collaborated; I made suggestions of icons to use as she talked through her lesson. She produced a large three ring binder that was organized into a year's worth of TPD lessons and opened to a collection of lesson resources that included an agenda, worksheets, videos, and samples of students work. It was also heavily annotated with notes in the margins of her agenda and other papers that ranged from pedagogical reminders to comments about a resource (e.g., "volume is bad on this video"). I suggested that she already had her workflow organized in a particular way and we were merely translating it, an idea that she immediately grasped.

At the start JL interjected the caveat that she was working with inservice teachers, which was a very different model than the university setting in which I developed the prototype workflows.

> JL: …it is a very different environment working with inservice teachers that are there because they are told they need to be there. They're not volunteering to be there…with the unions and the associations in the different districts there was certain things that you can ask them to do on their own time, but it has to be a suggestion; it can't be a requirement…so I could talk to you about what I did with this, and it's still very effective, but it certainly did not have all the parts of the workflow, like the required readings; you can't do that with a captive audience…what they did outside the time that they were released to be with me would probably not be reflective of what they would have done if they had been in a graduate course getting credit.

Basically she suggested that elements of the workflow that I had presented would not show up in a workflow she produced; she didn't do some things that I had put in the prototypes because she couldn't. But that was exactly the question that I was pursuing – could the system be used to document what went on in a workshop, seminar, or other type of professional development environment?

The answer was not only yes, but it turned out to be easier to put together a workflow of the all-day workshop than it had been for CM's graduate online course because it was more tightly structured in terms of both activities and time. There are a couple of possible reasons for this. First, inservice time is extremely valuable and everyone wants to maximize the learning that takes place. Second, JL might believe that learning best occurs in highly structured teacher-directed learning environments and designed her lessons accordingly. Regardless, JL was able to easily construct a workflow representation that showed the order of tasks her teacher-learners engaged in, attribute the specific resources they used during the task, identify what outputs resulted from a task, and even assign a timetable for every task in the lesson. As we talked through the lesson she occasionally provided rationale for a task, resource, or the order (e.g., “I wasn’t going to have them [view the video] and then go to lunch and then come back and talk”). There were only two situations she described that we couldn’t represent with the current lexicon. The first was breaks or lunch, which are deeply engrained (and sometimes contractual) activities in teacher inservice. The other was the lack of a tool icon for the document camera that teacher-learners used to present their work. These can be added to the lexicon.

A tension in part of the representation. When the workflow representation of the TPD in-service was completed JL expressed concern that it didn’t accurately represent the way that she did certain combinations of tasks, for example the sequence of watching a video and discussing it. She saw the tasks as tightly intermingled; she would show part of the video, stop and discuss, show some more video, stop and discuss, and continue that way until they had watched and discussed the entire video. In her mind that was significantly different than the way we had already represented the view-discuss sequence as linear tasks (the two right-most icons in Figure 21(a)). We discussed and agreed that since the tasks were being done *almost* concurrently it would be acceptable to represent their relationship with closed branch and merge dots (which indicate that both activities had to be completed before moving on), as shown in Figure 21(b).

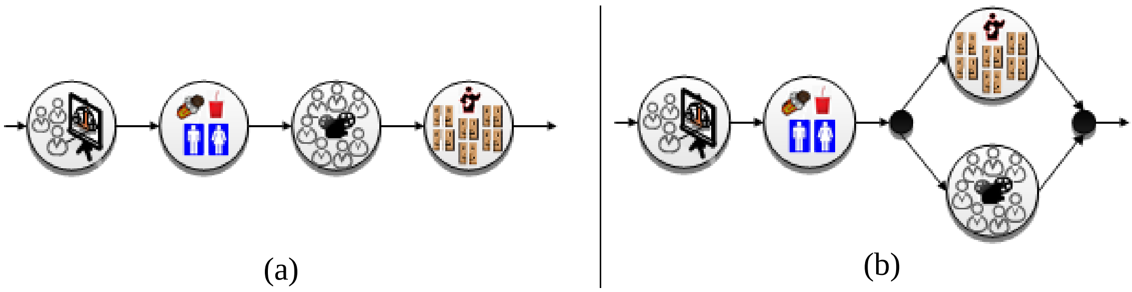

***Figure 21.* (a) A segment of JL's original representation shows a small group presentation followed by a break, and then the whole group watched a video followed by a discussion of the video. (b) JL's suggested modification to the representation to show viewing and discussing the video as concurrent tasks.**

What this episode illustrates is that a relative novice with respect to the WVS, but who had expertise in designing interventions, could evaluate her visual representation and detect potential errors, which suggests that the WVS facilitates "visual thinking".

Sharing workflows and associated tensions. I asked JL, as a teacher educator, what would be useful about having workflow visualization at her disposal?

> JL: I don't think, for *me*, it would be any more useful than what I have. However, if I were trying to show it to someone else and they want to see my workflow, it would be easier for them to follow this (pointing to her sticker workflow) than it would for them to follow the binder...

She elaborated this idea by emphasizing that the visualization could be more accessible to others because they are less personal than the organization of her binder which, she suggested, others might have trouble decoding. This was similar to arguments that both CM and RS had made in other cases that the icons, once learned, had the potential to provide a universal and easily interpretable language for *sharing* interventions and ideas about teaching and learning. When I asked her what she would need to include with the workflow visualizations if she were to share them with others she laughed and said, "Me! I'd send it with me!" She went on to explain and give an example of what she saw as a limitation of the WVS:

> JL: They might not really understand what kind of discussion we had. It says here that we discussed the solutions, but they may not really understand

> what *I* (did)….they would understand it by their own interpretation. I mean, this is very good, but not enough to explain how things were used, and I think that's important too.

Her comment aligns with those made by others of the need to be able to more fully describe a rationale for tasks or resources or pedagogical moves that took place during the implementation of the lesson. I asked JL about a feature that would allow her to annotate a workflow as she reflected after teaching the lesson and she said the idea was consistent with what she already did; writing notes in the margins and on post-its in her binder. When I suggested a mechanism for double-clicking the icons and adding information about the tasks, she immediately said, "Yeah, that's like Snapfish…" (a photo-sharing website); she was completely comfortable with the idea.

Summary. Although succinct in her interactions with me during most of our afternoon, JL showed that the WVS representations could pique her natural interest in the interactions of students in learning environments. Furthermore she showed the ability to quickly make an accurate initial interpretation from an intermediate representation of a lesson that she had not designed or taught. Of course this was a very limited trial but it is noteworthy that, in this case, the WVS did what it was designed to do.

Additionally, JL demonstrated that the WVS has the potential to visually represent interventions that have a different framework than a university online course. This case also suggests the possibility that highly scripted teacher-directed interventions are more easily and accurately represented by the WVS than more "constructivist" interventions. This distinction would likely be equalized by introducing the ability for instructors to append or annotate workflows as or after an intervention is implemented.

Case #4: Systems Analyst/Software Developers. This case, unlike the previous ones, is a compilation of two discrete discussions. One was with MK, a graduate student of CHS, who was a former IBM computer systems analyst and currently works as an assessment coordinator for an large urban school district. The other was with software developers from Rutgers Libraries who are charged with developing the interface for the VM. ChM is the Programming Coordinator at Rutgers Libraries and YY is a senior database programmer. ChM had taken part in previous conceptual discussions of the WVS; YY had no previous experience with the VMC project so ChM and I took some time to explain how my work fit with the tools they were developing.

Major topics covered in these less-structured discussions addressed two of the tensions raised explicitly and implicitly in the previous cases and introduced another.

How do users develop expertise with the system? This was a question MK posed during my impromptu overview presentation in a common meeting area outside of the suite of educational psychology offices at the Graduate School of Education.

> MK: …that blank screen design from symbols and having it work well implies a certain amount of expertise on the part of the designer. If you want to have a novice be able to use the tool like an expert… In other words, how do you get a novice to jump into being an expert?

Then he offered potential answers. First, he suggested that a help section be designed that included proactive tutorials for such questions as "how do you get the most out of this system", or "how do you interact effectively with this system?" To help a novice user gain expertise, he suggested that the tutorials include categories of scenarios:

> MK: Once you start pressing into that you'll probably find that you need to say something about, if you want to do this, here's some things that an expert would do. If you want to do this, here's some other things that an expert would do. And if you're not sure what you want to do, here's some things

> that an expert might do. So, just a thought on what to put in the help list that's more open-ended than, here's a task, here's how to do it.

Second, he talked about helping people learn the symbol language by organizing the lexicon by meta-characteristics – shape, size, color, dimension – and making the distinctions explicit, i.e., circles always mean task and blue always means input.

> MK: [I]f you were to take all of the symbols that you're using here, which you've taken pains to make consistent, then, because you're using it all the time, you can look at a symbol and see where it's position is in the whole information structure. Now it looks like if you were to identify meta-characteristics for that niche, that symbols for some meta characteristic share some aspects of their symbol. Inputs and outputs have color; they're color coordinated. And here you've got; so, assessments have this shape to them. So what I'm suggesting is to make it explicit. To help people learn the symbol language. And also, once you get them all laid out, to take a look at it and see if there's a way to simplify it. Because the bigger the lexicon, that harder it is for people to deal with it.

And third, he talked about the implied design architecture of the WVS that requires a certain amount of expertise to translate a blank screen into a visualization by dragging and dropping and connecting icons. He recommended building partial templates that help novices learn about the design architecture while building workflows by automatically adding related parts of the representation when a user selects core parts:

> MK: [W]hat you want to have is expert rules embedded in to the response of the system to the novice dragging things. So as an expert you know that if you drag this particular symbol over, you're going to need this other stuff. And so, [a novice pulls] that over and it sort of creates maybe a slightly grayed out template that comes with that. So now the novice is going, 'oh, you mean that implies all of this?'

For example, task icons are always paired with input icons so when a user selects and places a task icon in a workspace, an input box is automatically placed with it.

How do you represent that the output of one process is the input to another? MK posed this question to me when I had explained that inputs were always colored blue with an arrow going in and outputs were always red with an arrow pointing out. He reminded me that in the truest sense of workflow, an input is subjected to some process that produces an output which in turn becomes the input for the next process, and so forth.

> MK: Would it confuse them or help them to see a particular icon in a particular color representing some piece of information…some object? Well it was red. And now I see it somewhere else and it's blue.

He concluded that likely was not problematic and that the color change might even help users to follow the input-process-output paradigm, but his question revealed a design tension I hadn't considered; how or *whether* to represent in a workflow visualization the *tentative* processes and outputs that are core to developing understanding about a targeted concept? For example, take the case where a student is asked to read a book chapter and then later apply what s/he read to the analysis of a video of a child solving a math problem. The initial task is to read; to process the words in a specific book chapter. The book chapter is the input. And the output? Presumably it is certain ideas or concepts in the chapter that are meant to be used in the next task. The outputs are *tentative* because unless we tell students what to read for explicitly we can't be certain what concepts they will extract from the reading. For that reason I never attributed outputs (other than compliance data) to information tasks (i.e., reading or viewing a video) in the prototype workflows, and rarely attributed inputs that symbolized knowledge acquired in a previous task either[13], even though we routinely (and oftentimes implicitly) expect students to do just that. This was noted in previous cases by the senior PIs and project managers when they called for more information about how resources were being used.

But it could be done with a "prior knowledge" image (which I would re-define more broadly as something like "acquire/recall/apply knowledge") associated with input and output

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[13] The exception has been when students were explicitly directed to use concepts from the reading to make an argument.

shapes. While a lesson designer can't know for certain what outputs a student will extract from a task (e.g., a reading), s/he would know what is *expected* to be acquired from doing the task and applied to the next task (or future tasks). To better document the design of an intervention for DBR, in addition to greater fidelity to the input-process-output workflow paradigm, the designer's expectation should be stated as an output of a task (or as outputs of multiple tasks) and may be explicitly or implicitly[14] represented as input to other tasks. Doing this would also provide richer information about the intervention, which is a recommendation from most of the people interviewed.

Design session w/software developers @ Rutgers Libraries. I did not do the PowerPoint presentation, but used the website (http://vmc.wceruw.org/workflow/workflow.html) and the workflow that JL had created to show the workflow building process to ChM and YY. The discussion with software developers quickly gravitated from an overview of my work and summary of my meetings with potential users to the potential design of an application to help users easily build and annotate workflow visualizations.

We talked through a number of issues, including drag-and-drop functionality to build a workflow piece by piece, access to icons and connectors, creation and access to a library of templates, how to connect resources to tasks, where to store or how to access resources, how to create a sub-workflow, how to create an micro-workflow, and how to import data into the workflow.

A simple whiteboard sketch of a potential user interface developed from this session for the tool is shown in Figure 22. The sketch shows is a specialized version of a drawing and annotating tool that has elements characteristic of diagramming programs (i.e., Visio or Gliffy)

[14] It is generally accepted that learners will recursively apply previously acquired knowledge to new situations as they see fit and it would seem to be redundant to state that for every task. On the other hand a lesson designer may want to make sure that a student uses particular concepts when doing a task and those should be stated as an input.

and visual annotation programs (i.e. VUE). With it a user can make a digital diagram that shows the elements and flow of an intervention by selecting task icons and connectors from menus and dragging them into a blank workspace. It would be possible to have a menu of templates, as MK suggested, that could also be dragged into the workspace and modified. The user could double-click on icons and open a new workspace window with the options to add links to resources that are used in the intervention and annotate elements as s/he chooses. The user would also be able to select and set up visualizations that use data that was generated from doing tasks during the intervention (i.e., micro-workflows).

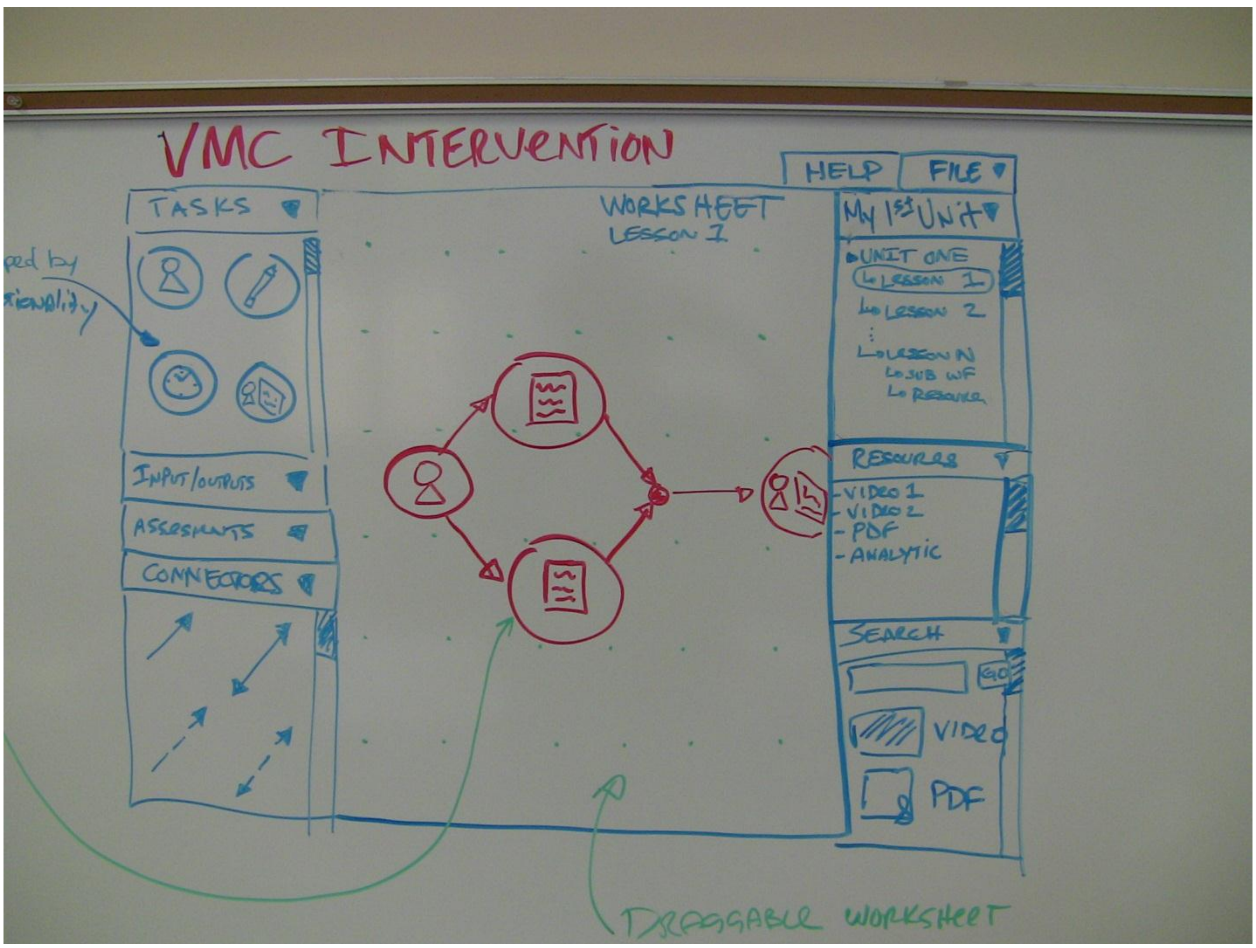


Figure 22. **Conceptual whiteboard sketch of a workflow building tool.**

That would be the extent of the workflow building applications functionality: to allow a designer/researcher/instructor to visually organize information and data about an intervention into an *intended* workflow. A designer/researcher could use other web-based tools (i.e., web forms) to annotate or add information to the *actual* workflows as, and after, they are implemented (we did not generate a sketch of such a tool.) This would be in addition to information that would automatically be captured by the WVS. As noted earlier s/he could use these web-based workflow visualizations to and identify points of interest and then apply more sophisticated analysis tools to a narrower, more focused slice of the overall data in order to inform potential refinement/redesign of an intervention.

Case #5: The HAL-O research team uses the WVS. I have previously documented the contributions of the HAL-O research team to the initial design and development of the WVS. The team also tried to use the WVS as a tool for doing design-based research on the HAL course with limited success. The sample of workflow visualizations created using the WVS allowed the team to see potentially interesting phenomena, but it was small, covering only one unit of the course. Because of this constraint, and the labor intensive work involved in producing even a single lesson workflow visualization, we were not able to examine potential patterns across a broader range of lessons or units in the course in a way that fostered confident lesson re-design or theory building. This made the WVS in its current state of development untenable as a tool for detailed or longitudinal analysis.

On the other hand, members found aspects of the WVS immediately useful for at least two purposes: sharing lesson designs and sketching student interactions as a starting point for further analyses. While it was time-consuming to create the image maps and hard-code the data that produced the layered display of data on clicks mouse-overs, it was relatively easy to use

Visio to create a workflow *representation* (i.e., visual image without interactivity) of a lesson. Both SD and I used workflow representations of lessons from HAL Online and other courses in talks and conference presentations delivered via PowerPoint and poster. When the presentation included a legend or slide explaining the icons, the workflow representation became a useful tool for communicating in a short period of time a great deal of information about a lesson or course. In a separate research project that involved data generated in HAL Online, JG used the WVS principles to sketch micro-workflow representations of the interactions of small groups engaged in a designed discussion activity. She coded her representation in such a way as to index sections of a transcript of the interaction. An outcome of doing this was that, like Barron (2003, 2007), she found it easier to see who and how group members contributed to the discussion and potential points to "dive into" the data. Like SD and I, she also found her intermediate maps were an efficient way to organize her data and to frame and talk about her research.

Can the WVS be used to compare implementations? The evaluation of the Spring '10 HAL Online course was conducted using information from several sources, including student performance data, student feedback, the instructors observations, team members observations, and analysis of samples of students engagement and participation. The prototype workflow visualizations of the "Amazing Learning Brain Part I: Children's Mathematical Thinking" unit were used on a limited basis to facilitate a part of the analysis. The unit included newly designed lessons that introduced VMC materials – a mathematics problem and video from the combinatorics strand - that were integrated with readings on brain development and problem solving to create a unit on children's developing ability to think mathematically.

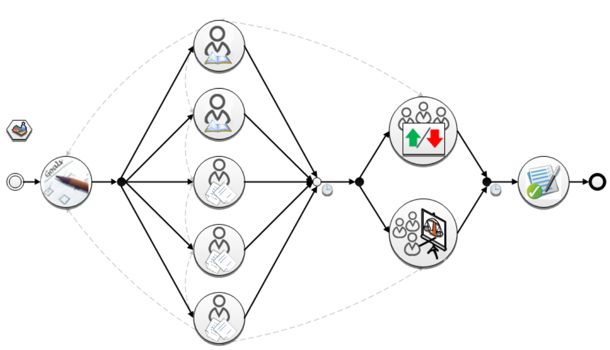
An observation shared by all team members was that the quality of the arguments made by some students and groups in the course assignments was low. For a course built on the idea of learning through argumentative discourse this was significant. Analyses of the micro-workflows of group discussions revealed (or confirmed group members hypotheses about) characteristics of individual's and group's arguments that led to our consensus about the low quality of their arguments. From the micro-workflows we all could readily see: (1) groups members who did not access resources (i.e. assigned readings or videos) or engage in the discussion; instead they tended to make cursory comments just before the due date; (2) low use of "real" evidence in arguments; while one or two strong individuals in each group did make thoughtful, well-structured posts, many students constructed arguments from "pseudo-evidence" or non-evidence; and (3) a general lack of connection between students over the span of a discussion. Several discussions people tried to start went nowhere, there were relatively few discussion threads that showed all group members contributing, and threads where everyone *did* engage tended to contain a number of trivial postings, e.g., "Thanks for doing the summary!" or "I really liked how you related the reading to that thing that happened to you in junior high…"

The research team debated a number of strategies for improving the quality of the argumentation that included:

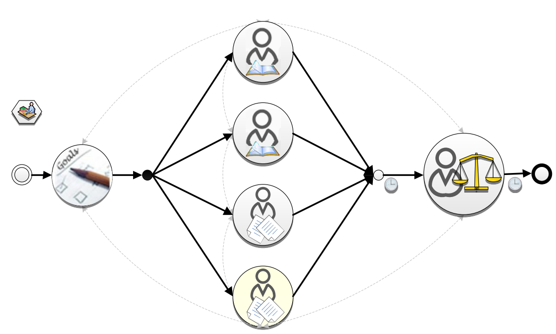
- be more explicit in assignment directions about interactions and use of evidence; perhaps assign (rotating) roles to students,
- focus more attention on argumentation, e.g., in the initial face-to-face class show examples of good group arguments and how individuals contribute to the structure,
- redesign tasks so the structure is more obvious to the students,
- outline expectations for timeliness and content of discussions but give groups autonomy to self-organize.

A major redesign issue that emerged from the observations and reflections of the instructor was to reshape lesson structures to make them more manageable – productive but not exhaustive. SD noted that as an instructor and as researchers BE, JG, and myself – who had all been teaching assistants for the course and pitched in with giving feedback – we worked hard to keep on top of things, and we had the advantage of knowing the course material. Students, she argued, had more to keep track of than us - new material, new big ideas to grasp - and trying to digest the way others present their ideas and give meaningful feedback was a lot to expect. She proposed a redesign of at least some of the lessons that included ideas from above –directions that mandated explicit times for posting and types of group interactions, and redesign of tasks. And she reduced the number of things we asked students to do in a lesson.

A question that I asked of the WVS was related to its ability to capture differences in implementations of a lesson or unit. I hypothesized that design changes across implementations should show up as structural changes in the workflow visualizations. The following workflow representations (Figure 23) of the "Early Brain Development" lesson in the "Amazing Learning Brain Part 1: Children's Mathematical Thinking" unit from Spring 2010 and Fall 2010 demonstrate this. They facilitate comparison of two lessons before and after redesign. Also shown are the sub-workflows for the analysis task "Making Connections between Development of Mathematical Reasoning and Argumentation".



(a) Spring 2010



(b) Fall 2010

Lesson level macro-workflows.

(c) Spring 2010 (d) Fall 2010

Sub-workflows for (c) presentation task and (d) analysis task.

Figure 23. **Comparison of Early Brain Development lessons.**

A brief inspection of the lesson level macro-workflows (Figure 23(a) and (b)) reveals four differences in the lesson structures: one less reading assignment: one reading assignment (shaded at bottom) is now recommended rather than required, the number of multi-part tasks is reduced from two to one; and the remaining multi-part task is done individually rather than as a group. A similar visual inspection of the sub-workflows associated with the presentation task in the Spring 2010 workflow (Figure 23(c)) and the analysis task of the Fall 2010 workflow (Figure 23(d)) also reveals easy-to-identify differences: students' are still required to recall prior knowledge and view a video, but rather than engaging in a group discussion they post an opinion about the question asked by the video, review the opinions of other group members, and then make a second post nominating one post as most interesting, perceptive, and convincing.

Two elements of the instructor's redesign plan can be identified from these intermediate representations: a reduction in the number of things students are asked to do, and redesign of the group presentation task to an individual analysis task. If the analysis sub-workflow in Figure 23(d) were interactive, clicking on the 'Instructions' icon would reveal additional design changes: explicit instructions are given for what lesson materials students should use in their analyses, what criteria needs to be represented in their nomination of an exemplar, and a specific timeline is given for accomplishing each task.

Ultimately the instructor and research team want to explore the broad question, “did the design changes lead to an improvement in student learning”, for which they will examine and compare data on how students used resources and what they said. This data is organized by micro-workflows which support both visual inspection of trends and more focused discourse analyses. In this case, micro-workflows would show a better distribution of students’ accessing data. Every Fall 2010 student accessed readings and video early in the lesson cycle - not the case in the Spring 2010 course – and made more timely (i.e., early) posting to the discussion forum. Although not within the scope of this dissertation, HAL researchers report that their design changes have improved argument quality in the course.

The point is, it appears that intermediate representations of different implementations of similar lessons (i.e., same goals, similar structure) have value for identifying differences that are not just superficial, but can facilitate deeper analyses regarding the effect of design changes on learning.

V. Summary/Next Steps

An important conclusion that emerged from each case study was that the Workflow Visualization System has the potential to make a strong contribution to design-based research and the learning sciences in the following ways:

- It transparently organizes a large body of data as it is generated into meaningful visual intermediate representations that support such processes as sampling, selective viewing, and pattern finding.
- It preserves data and analyses in the context of how they were collected.
- Archives are sharable, which promotes collaboration.
- Standardization of a method of organization and visualization facilitates interdisciplinary communication and will eventually allow for virtual experimentation mining data across projects.
- Workflow visualizations created by learning scientists will scaffold/promote good evaluation and design practices by educators from other fields who use a course management system to deliver instruction but aren't familiar with DBR.

Using an appropriate organizing metaphor and visual frameworks the WVS utilizes networks and hierarchies to efficiently show the interrelationships of the large number of diverse variables that typically make up an educational intervention. This includes the way that variables and elements of an intervention are *intended* to interact as represented in a macro-level workflow representation, and how the lesson is *actually* implemented by the instructor and students as represented in micro-level workflows. Visualizations of intervention *processes* (e.g,, when or how often students access lesson resources, or music score representation of a small group discussion) facilitates efficient detection of patterns or points of interest in an intervention. In online systems that collect and archive student-generated *products*, the system can make such data readily available and easily retrievable for deeper analysis. The WVS supports the sharing of information about interventions: within research groups (potentially distributed across a large distance) to support hypothesis building and discussion; across large-scale projects where multiple instructors are implementing the same materials in similar (but not identical) stings, to sharing experiences and "best practices"; or to efficiently share details of interventions with a large conference audience.

This work is timely. The 2011 edition of "The Horizon Report", a collaboration between the New Media Consortium and the EDUCAUSE Learning Initiative, identifies *learning analytics* – "…a variety of data-gathering tools and analytic techniques to study student engagement, performance, and progress in practice…with the goal of using what is learned to revise curricula, teaching, and assessment…" (p. 6) – as a technology to watch for teaching, learning, or creative inquiry. My work on the WVS is also consistent with a recently announced $200 million "Big Data Research and Development Initiative" by the White House Office of Science and Technology Policy (2012). The initiative calls for state-of-the-art core technologies to "collect, store, preserve, manage, analyze, and share" huge quantities of data and "…transform teaching and learning" (p.1).

Review

In this study I designed, developed and evaluated the efficacy of an web-based workflow visualization system to: 1) address the challenges of visually representing the large number and range of elements and their intertwined relationships in a designed intervention; 2) assist researchers taking a design-based research approach in achieving control in the manipulation of variables, which occurs between implementation phases of the design process; and 3) provide sharable models of interventions that are adaptable to local contexts.

Assumptions. For this study I made the following assumptions:

- Educational interventions have workflows, which can be expressed visually to serve as intermediate representations of a learning environment that is the product of a designed intervention.
- When an intervention is a product of design-based research, there are, in general, variables or elements of the designed intervention for which data need to be collected for analysis, and these are identified in the design-based research literature.
- For interventions that take place in an online environment facilitated by a course management system (CMS) such as Moodle, many details of the intervention's workflow are captured in the CMS's modules and activity logs.
- CMS modules and activity logs can be mined to recover descriptive data about workflow of an intervention that can be represented in web-based workflow visualizations that facilitates; 1) analysis of workflows as part of the iterative process of research-based design, and 2) sharing of adaptable interventions.

Study phases. The initial phase of the study consisted of two design and development cycles that were extensively vetted in HAL-O research team meetings. In the first cycle workflow mining techniques were applied and workflow models following approaches from business-related literature were developed to represent a lesson from HAL Online. Limitations of business workflow models to represent the tasks and interactions of educational learning interventions were identified and alternative models were explored that captured applied science-related characteristics of workflows (i.e., reuse and making innate processes more explicit).

Control flow characteristics of the business model – tasks and sequence - were retained and visual elements were gradually added that provided cues about the resources that were used in the intervention, how the resources were processed, and how the data that resulted from processing could be accessed and reviewed. Once I had codified a procedure for building visual icons, I was able to move into the second cycle of design and development on a workflow representation system that was unique to interventions designed for educational learning environments. In addition to systematically incorporating information design principles – micro/macro readings, layering and separating, small multiples, and use of shape and color – I utilized a suite of web-based tools to introduce interactivity to the workflow visualizations that I was hand-rendering. Cascading style sheets, JQuery libraries, java script, and html coding were used to hide and reveal information in a structure that was both hierarchical and networked.

It is important the know that models of HAL Online lessons that emerged from the second design and development cycle are *prototypes* of what a functional workflow visualization *could* look and act like. There was no expectation on my part that the WVS was finished and that designers or instructors would employ the same labor-intensive procedures I had used to create their workflows. Automating the processes of building workflows and populating them with data was work I assigned to my next post-dissertation design &development cycle. Work in that cycle would be informed by the results of the evaluation phase of this study. Of principal significance is the value that potential users give to the prototypes for supporting their research on designed interventions, project management, and sharing interventions or best practices. In that regard subjects affirmed, with suggestions for next-iteration design improvements, the potential of the prototypes and the WVS to be a tool that could improve efficiency by organizing large amounts of diverse data, and enhance insight by providing visualizations that reveal patterns or interesting points in the data. Their caveats are discussed with the study research questions below.

Research questions. The study was guided by the following research questions. I will discuss each question in terms of the results from the design and development or evaluation phases of the study.

What elements/variables of a designed intervention are important to represent in its workflow visualization? Two frameworks contributed to this answer: the Social Infrastructure Framework, and the Workflow Management Coalition's meta-definition of core workflow elements. Their relationship to one another and to elements in the lexicon of the WVS is documented previously in Table 4. Observations made by several subjects during the case study interviews suggest that the WVS may not be sensitive to some elements of the SIF, particularly those that would reveal constructivist pedagogical strategies. By adding the ability for designers and instructors to annotate tasks and resources or modify the workflow post hoc in the next development cycle, these concerns should be alleviated.

How is workflow information and data mined from the CMS-supported intervention converted into a workflow visualization? Currently the process is done by hand and was described earlier. An important related question that nearly all of the subjects asked in the interviews was, *who* is going to convert the data into a workflow visualization? Or, how were lesson designers or instructors going to build and add data to a workflow visualization? The subjects all favored the idea of a drag-and-drop tool. Features that potential users suggested and developers discussed with me mirrored the functionality of tools that were familiar to them such as presentation software and cloud repositories for photo and music albums. The project managers, a former systems analyst, and software developers provided insights about how to design such a tool. Ideas included forms that would open on a double-click into which instructors could type descriptive information or upload images, templates that would help novices understand the relations of workflow elements, and layered workspaces in which designers could build sub-workflows and set up micro-workflows. However, CM, MP, and JL (a PI, a project manager and a field-based teacher) all explicitly said they would not use such a tool to *design* interventions, which implies they would have to create a lesson in some other medium and then somehow convert the lesson plan into a workflow visualization. This replication of lesson elements from one system to another doesn't seem worth the cost. I hadn't thought of this at the time of the interview – like the others I envisioned a drag-and-drop tool – but as I reflected on particularly CM, CHS (a PI), and MP's comments that instructors wouldn't do additional work to set up a workflow visualization I concluded two things. First, instructors of online (or hybrid) courses were already loading resources and suggesting a sequence of lesson tasks into some kind of course management system, and setting it up to collect data. This typically involved filling information into forms and WYSIWYG workspaces and uploading files. If these forms could be modified to incorporate the WVS rules for building workflows, the lesson designers would not have to replicate the design process; the WVS would interpret the data entered into the CMS and automatically create the workflow representation, complete with all the lesson information (i.e., goals, readings, video, websites, rationale, etc) associated with appropriate task icons. All of the workflow icons could be set up for annotation; a form would open when an instructor double-clicked the icon that would allow information to be added at any time. Sub-workflows could also be built automatically and data that is generated and stored in the CMS database as students engage in an intervention could be automatically mined and displayed in micro-workflows or other appropriate representations (i.e., tables, graphs, or charts). The second thing I realized is this process I'm outlining is very feasible because, in essence, it's what I did to create the prototype workflows. The Moodle CMS that is used for the HAL Online course displays lesson information in a template that utilizes html display (often text) and links to lesson resources. Moodle has a small library of icons that it assigns to resources or activities the designer chooses from a drop-down menu; it's reasonable to think the same mechanism could be used for task icons. The CMS also collects data about every user event and displays it in reports and tables. These were the sources I "mined" and converted into workflow representations and tooltip displays. This led me to conclude that workflow visualizations should and could feasibly be created automatically through data-mining algorithms that use data created as a by-product of course development and student participation with a CMS (such as Moodle).

What level of context of a designed intervention needs to be represented in a workflow visualization in order to support analysis and sharing of the intervention? What level of abstraction needs to occur in a workflow visualization in order to support generalization (and reuse) of workflows, or elements of workflows? To what extent does a workflow visualization methodology need to balance context of an intervention with abstraction? In the prototype workflow visualizations I showed lesson goals, assessments, details about the workspace (i.e., online or classroom), and what resources people used to do lesson tasks. The lesson designers/instructors wanted more "how" and "why" details; as CM said, "You show what they did, but not *how* they did it." The project managers wanted the ability to gather context data from instructors that would explain differences in designed lessons and the actual implementation, if they existed. If sharing interventions or their outcomes with others, JL said she would send "herself" with the workflow visualizations to provide both design rationale and explanations of how the actual lesson implementation went. The ability to annotate workflows and elements within a visualization should facilitate an increased level of contextual information.

The first representation of a WVS workflow that a user sees is a high-level abstraction that has the appearance of a flowchart where the shapes, sizes, and (sometimes) color of icons, and the way they are connected, give visual clues about the overall structure of an intervention. Symbols within the icons provide meaning and facilitate "micro-readings" (Tufte, 1990) that differentiate tasks, resources, or outcomes by pointing to contextual details (i.e., an assigned reading, an implementation strategy, and transcript of student work). Two lesson-level representations could have identical structure and icons, but open to entirely different assigned readings, videos, or other resources when the task icons were moused-over or clicked. Or, as MP and JL both observed, the order of otherwise similar lessons could be slightly different, and the WVS seems to be sensitive enough to pick that up. While case study subjects did suggest a few modifications to the generalized icons, they all grasped the logic of the high level generalized representations, no one more than JL who recognized it was equivalent to how she interchanged specific content into a basic seminar/workshop structure that she used with inservice teachers.

An assumption about the users of the WVS visualizations is that they will use them for some specific purposes: to share lessons and details about implementation with other teachers, designers or researchers; to study and compare designs in order to help make design decisions and develop or test theories about learning or instruction; and to help organize and archive data (instruments, test results, online discourse, etc.) from lesson implementations, to facilitate data analysis and reuse. To respond to the varied needs of potential users the WVS was designed to layer information and data in such a way that if a user wanted particular details s/he could click or scroll and drill down into the hierarchical and networked structure to supply or reveal it.

Higher layers would be appropriate for sharing intervention whereas the farther one "dug down," the more data specific to tasks and interactions would be revealed. This is not to say that higher level representations aren't used for research, but only that data that would be subject to more rigorous analytical techniques would be intentionally less accessible to someone who simply wanted to adapt a lesson. As a researcher, CHS suggested that this was a desirable feature, as long as the user knew that the data was embedded in the representation and how to get to it.

Can workflow visualizations capture and show differences in interventions that may lead to theory-based explanations of differences in outcomes? As shown in the HAL-O case study, the WVS can show differences that result from changes to an intervention. And from a discussion initiated by MP in the project manager case study, it seems likely that the WVS would also capture differences in the way individual instructors "interpret" the flow of a lesson. However there is not enough data to say if the ability to capture or show these differences would lead to theory-based explanation of outcomes. In the case of the HAL-O research team we found that as we tried to follow an interesting pattern we saw in one visualization (e.g., a micro-workflow) we did not have an adequate number of samples to pursue conclusive analyses. At this time and without automated workflow mining, the labor-intensive work needed to create such samples of workflows is not practical.

Can the workflow visualization approach developed in this study be adapted to create intermediate representations of interventions that take place in other contexts and learning environments, e.g., entirely face-to-face environments or short-duration professional development seminars such as occur in the larger research project? One of the five prototype workflow visualizations was created post hoc from a face-to-face class meeting. In the project instructor case study JL built a workflow representation of a teacher inservice she periodically teaches, so my answer to this question is a qualified yes. As MP and RS discussed in the project manager case study, the face-to-face environments will require different mechanisms for representing the kinds of “on-the-fly” pedagogical decisions that get made and that alter lessons in unforeseen ways. Additionally there may need to be more manual mechanisms for the functions that a CMS would do automatically, such as collecting samples of students’ work and interactions. So although the WVS is built to take advantage of the data collecting properties of a CMS, it could potentially be adapted to classroom and seminar environments.

Next Steps

As I noted in the introduction, the next design and development cycle will require resources beyond my current capacity. I submitted an NSF grant application to support the work which, while not funded, garnered positive reviews. The program director wrote, “…your proposed work could make the vast amounts of data generated during Design Based Research (DBR) more useful to researchers, students and others. The proposal made a compelling case that visualization of data would be an innovative and useful approach.” (E. VanderPutten, personal communication to proposal PI, October 12, 2011). Since this initial proposal I have done additional work with the WVS that will address the issues raised by the reviewers and have re-submitted the proposal, which is currently under consideration.

Part of the work I am currently involved in is a collaboration with instructional designers and programmers from the University of Wisconsin – Madison’s Division of Information Technology (DoIT) on a pilot study to automate the collection and representation of student performance data in an engineering programming course. In this case the instructor would like to see visual displays much like micro-workflows that show what lesson modules individual students are accessing, how much time they are spending on the modules, and if there is a useful correlation between how much time the students are spending on the lesson module and their performance in programming labs and the course in general. On a pragmatic level, the instructor would like a tool that would identify students who may need early intervention in the form of support in the lab or required office hours with the instructor. For me this is a case study to explore if and how instructors can use the WVS to better understand their students' engagement in their course and how that influences their learning.

The positive comments of the NSF reviewers and the expressed desire of the DoIT team to use my model of workflow visualization in their pilot study (they invited me to be part of the study) suggests that the WVS has the potential to be influential in a number of ways. First, it can make the data organization processes of DBR more systematic and facilitate early detection of patterns and points of interest in the data that lead to more focused analyses. Clean visual representations may also help researchers better see and describe the relations of elements in a complex environment, which can lead to a higher degree of control as elements are manipulated during re-design cycles. Second, the representations that emerge from the system can facilitate more productive and efficient sharing and high level comparison of designs and implementations of interventions. Third, as noted earlier, the WVS is an early example of the emerging field of learning analytics which focuses on creating visual models from disparate data of students' interactions with learning systems that give instructors insight into the effect of their instructional designs on student outcomes. In a keynote address at a teaching and learning symposium the director of academic computing at the University of Wisconsin – Madison used images of my workflow visualizations to illustrate what learning analytics can look like.

The data gathered from the cases in this study that I have reported will be influential in shaping the next design and development cycle of this work after which the power of workflow visualization to support DBR will be more fully realized.

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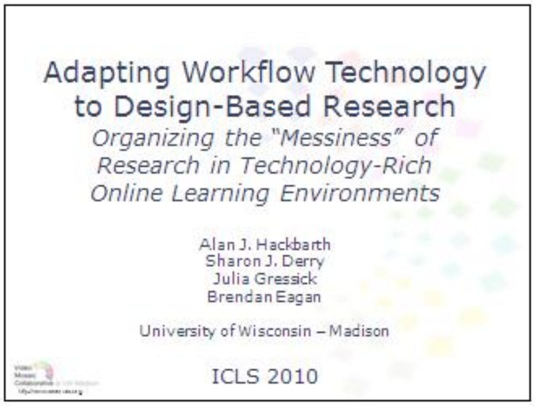
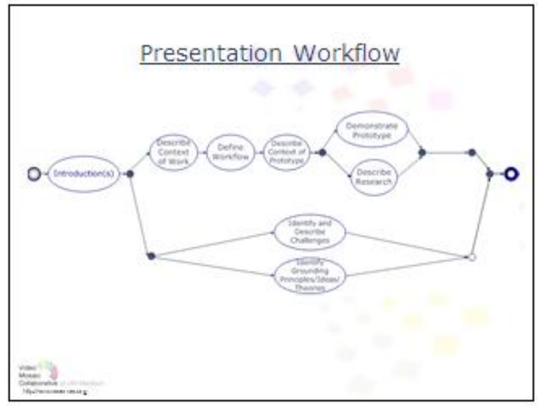
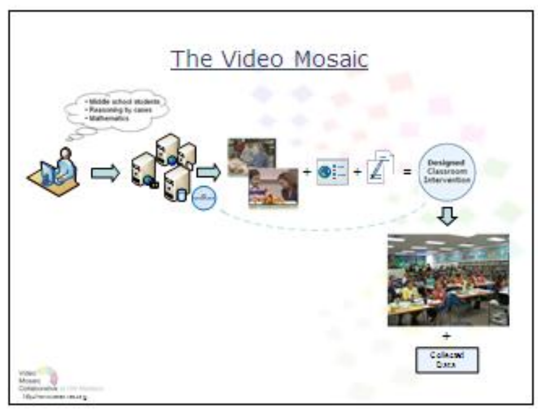
Appendix A

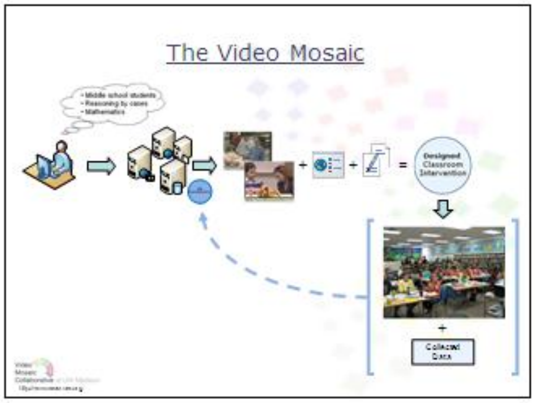
Workflow Presentation



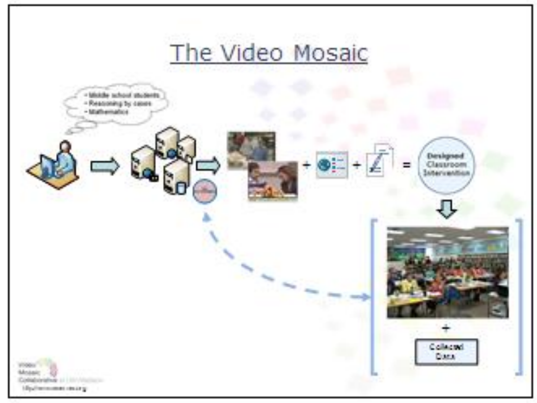




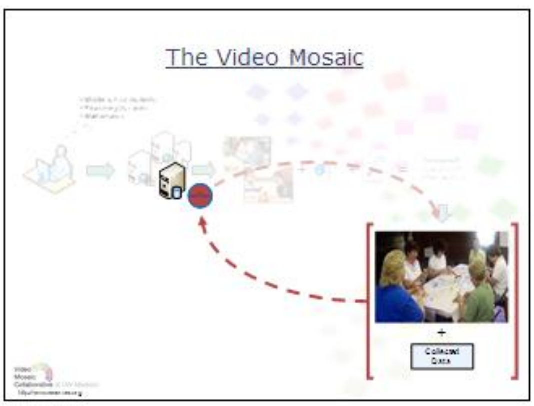
The Video Mosaic is a tool currently under development that will allow users (i.e. teacher educators) to search a repository of videos and choose clips that they can then combine with other tasks (e.g., readings, problem solving) to build an intervention. The designed intervention is then stored within the VM, privately at first, but it may be made public at a later date. The intervention is applied in a learning environment – a course, seminar, or workshop, for example – and data is (or may be) collected about the implementation.



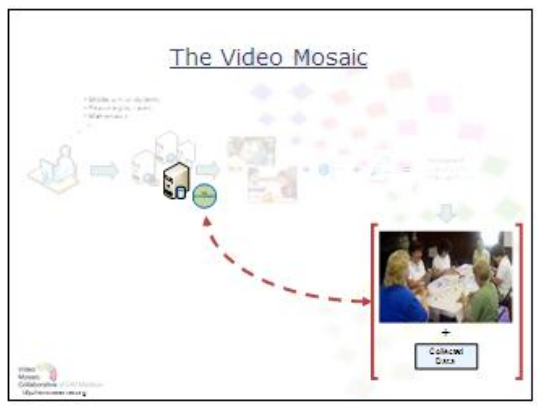
Collected data is added to the record of the implementation stored in the VM.



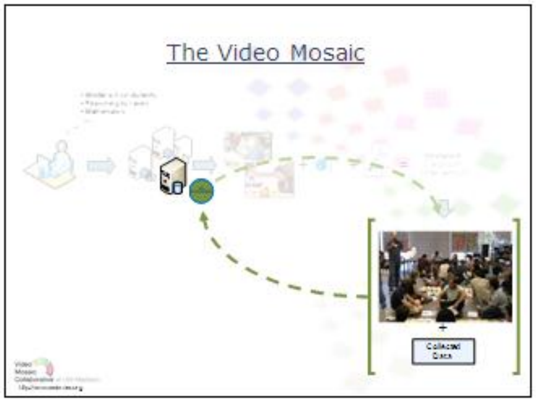
The data about the implementation may be studied and used to make changes to the design of the intervention.

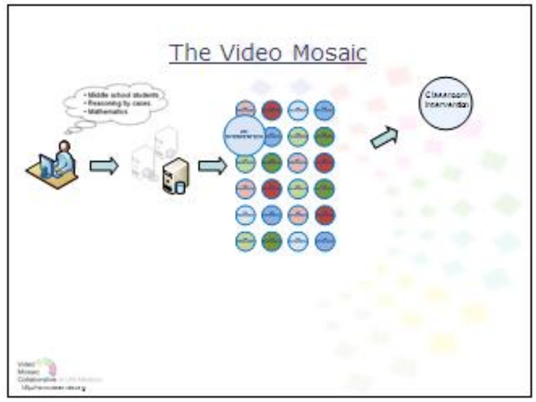


The new design will then be implemented in a new (similar) learning environment and data will be collected. An iterative cycle of design-implement, analyze, redesign, re-implement takes place until the intervention becomes stable. At this point it may be shared publicly.

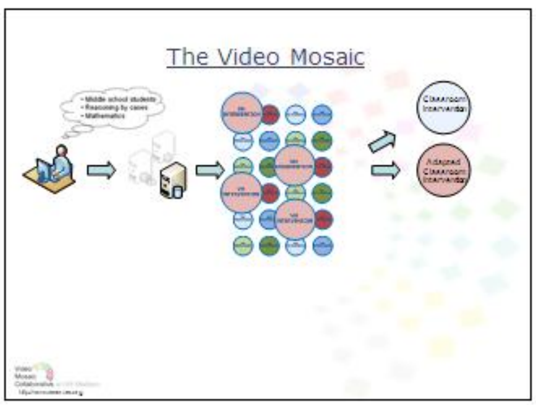


Once again, the data about the implementation is studied and used to make changes to the design of the intervention.

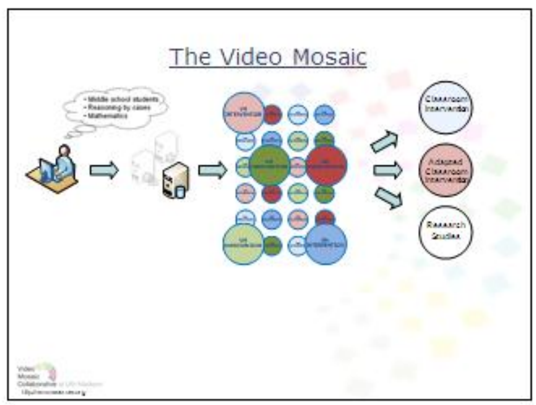




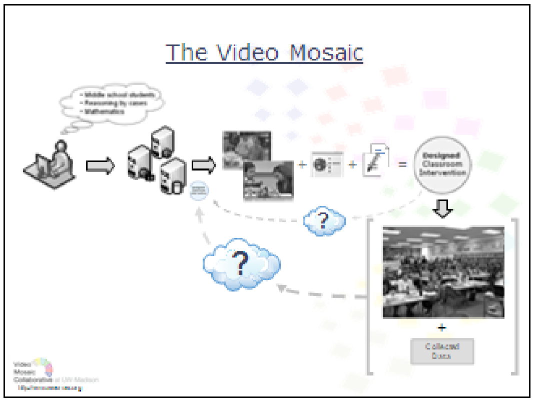
In time, the VM will include a collection of interventions that have been successful that users may access for a variety of reasons. For example, a teacher educator may adopt an intervention as is to use in her/his course.



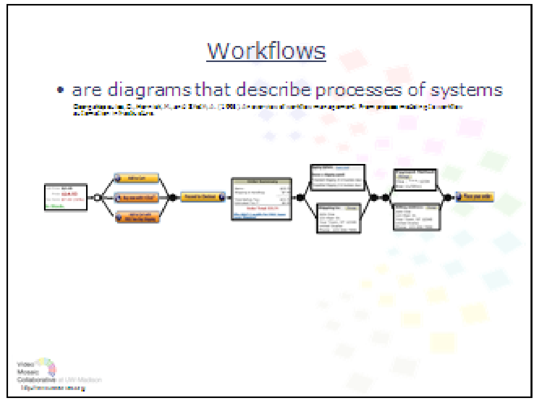
…or s/he may adapt an intervention by combining parts of several interventions or by substituting resources.



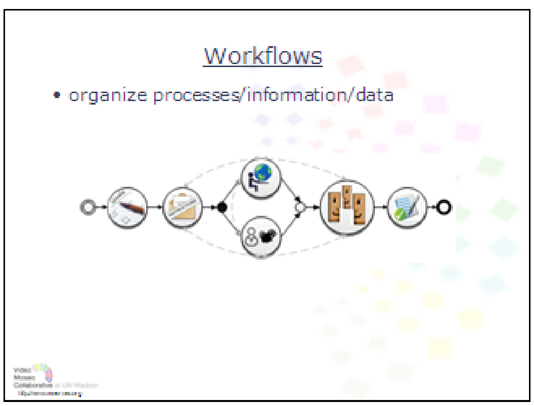
…or s/he may do research across several interventions.



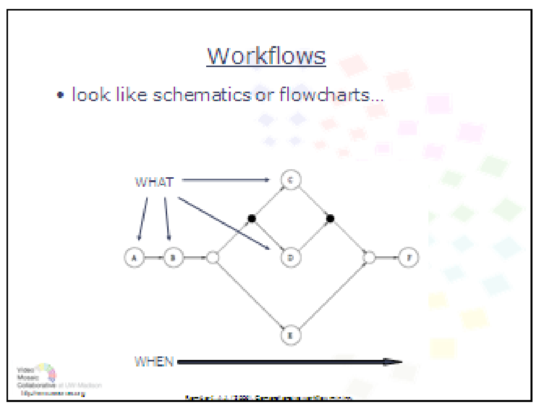
The questions that my work addresses is, "What does the representation of the designed lesson look like?" and "How is collected data represented?"



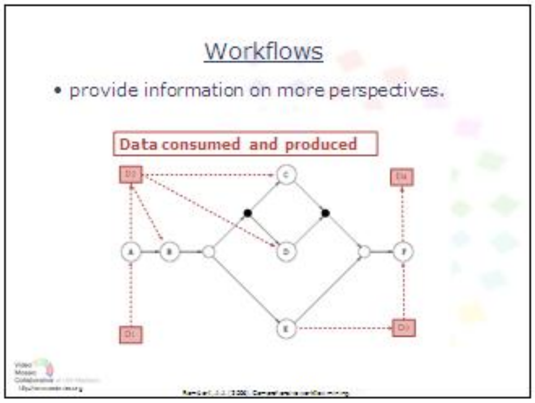
My work uses workflow technology to build the representations of learning interventions. An example of a workflow is the steps that a buyer completes on an e-commerce site.

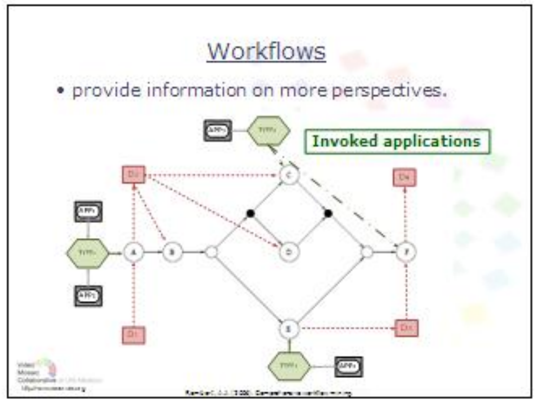


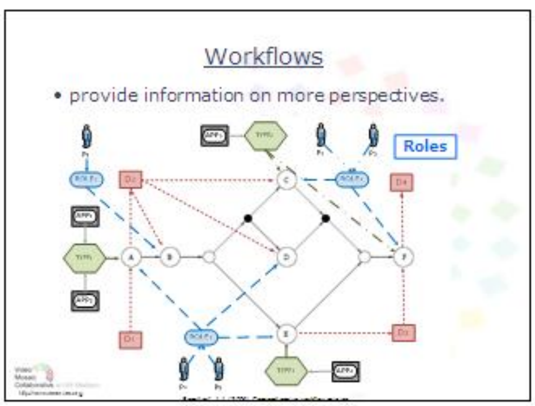
Workflows organize tasks designed to accomplish a goal into a sequence and attaches resources needed, and data about the tasks proximally.



In fact, a flowchart is a type of workflow that focuses on two dimensions; what happens in a sequence of tasks, and in what order (when) things happen.

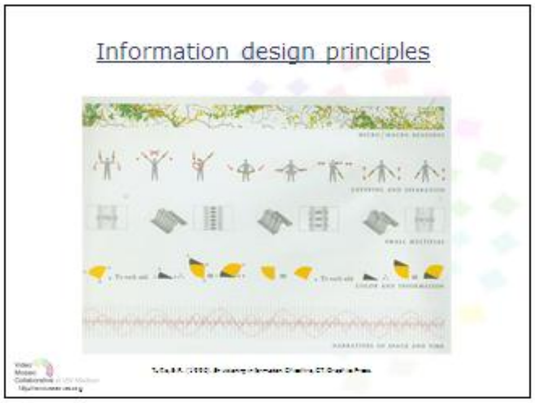




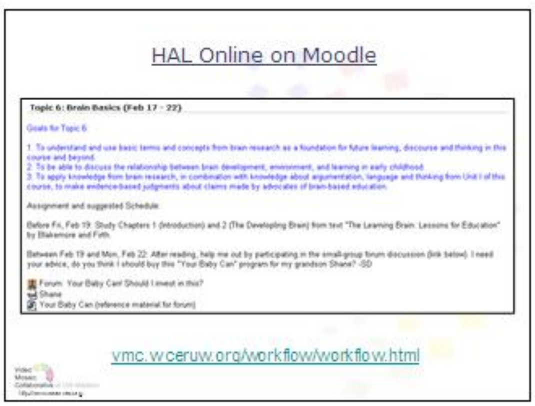


Or information about roles that individuals take on to accomplish a particular objective, and maybe information about the individuals themselves. The power of workflow representations is the depth of the information they can provide.

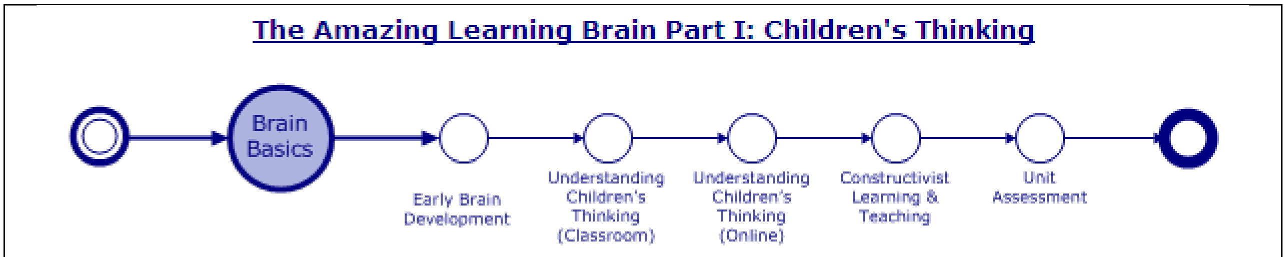
Cultural Beliefs How learning and knowledge are conceptualized.
Practices The ways in which teachers and students engage in activities.
Socio-techno-spatial relations The organization of physical space and technology workspaces as they relate to teacher and student interactions.
Interaction with the “outside world” The online and offline ways students are able to interact with people and be influenced by events outside their immediate classroom environment.



I also used Tufte's information design principles to design the visual elements of the workflow representations from the design and distributions of the icons used to represent tasks, inputs, and outputs. I used JavaScript and Cascading Style Sheets to layer and separate parts of the workflow, color to draw the viewer's eye to certain aspects of the workflow, and distributed small multiples over space and time to show how individual learners engage in the designed intervention.

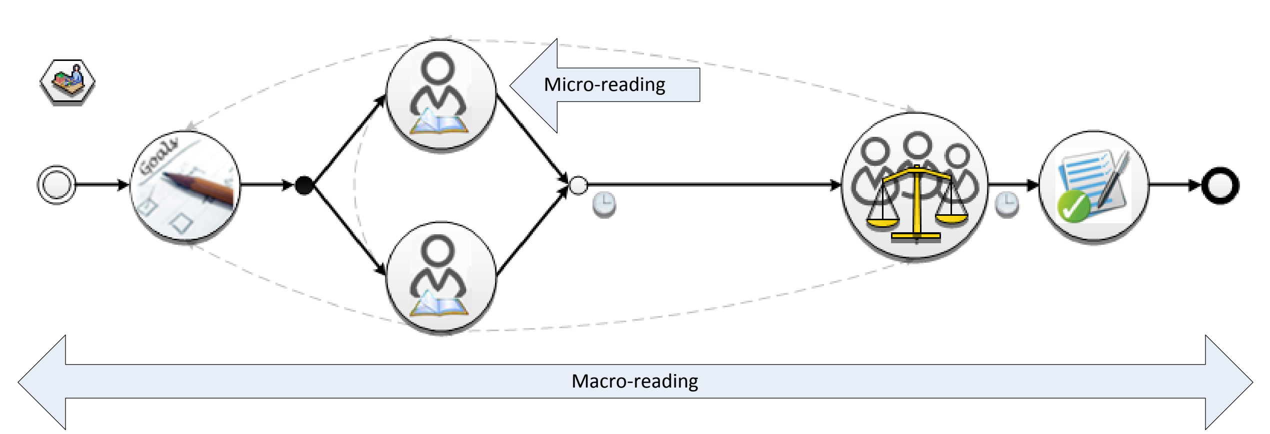


This is a lesson module in Moodle; what students use to get instructions and access resources. The link takes you to the website that demonstrates the prototype workflow representations that I have developed.

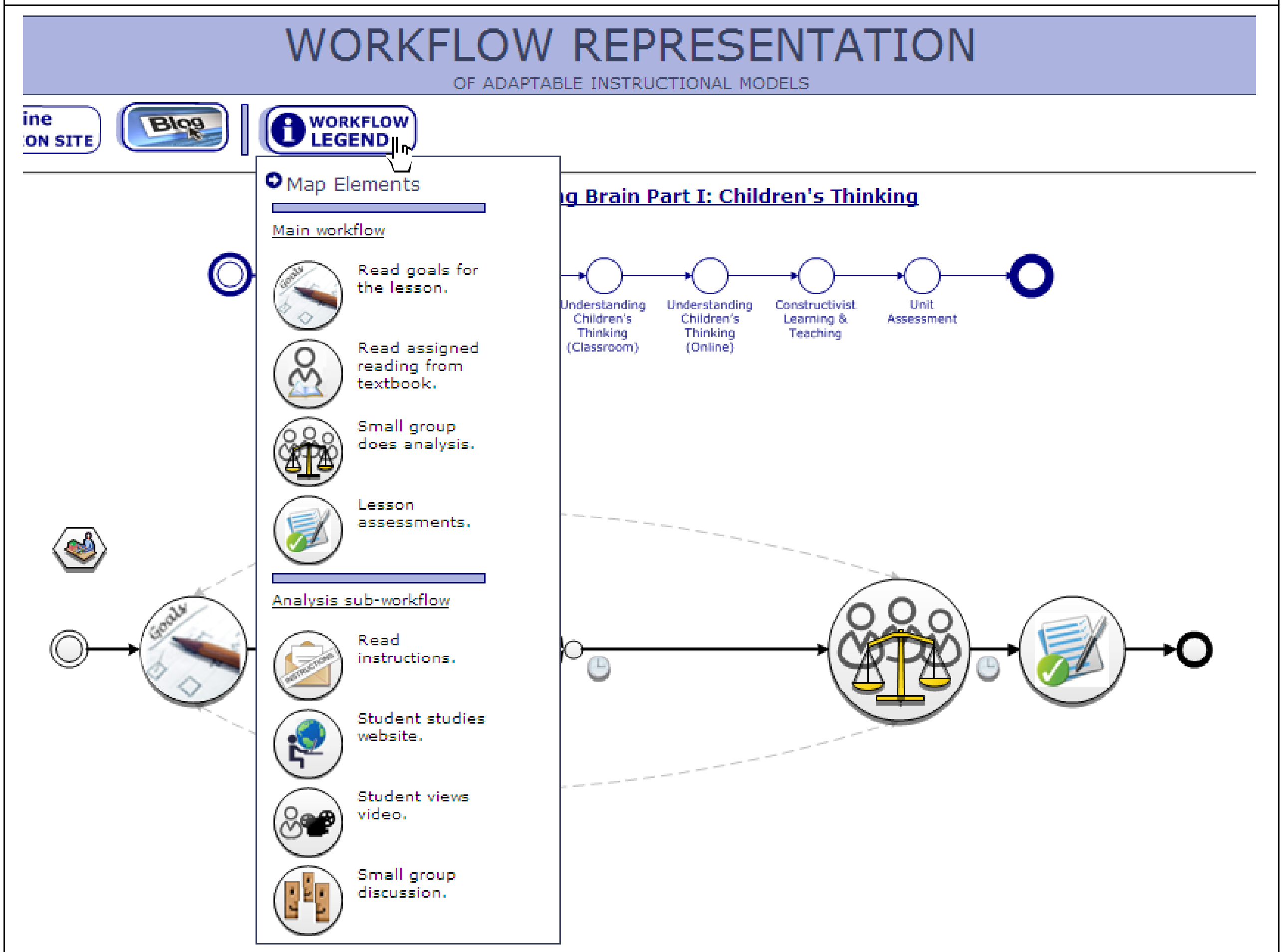


***Screenshot 1*. The unit workflow.** Positions a lesson within a unit and serves as a navigation tool; clicking on a lesson's circular marker opens that lesson workflow.

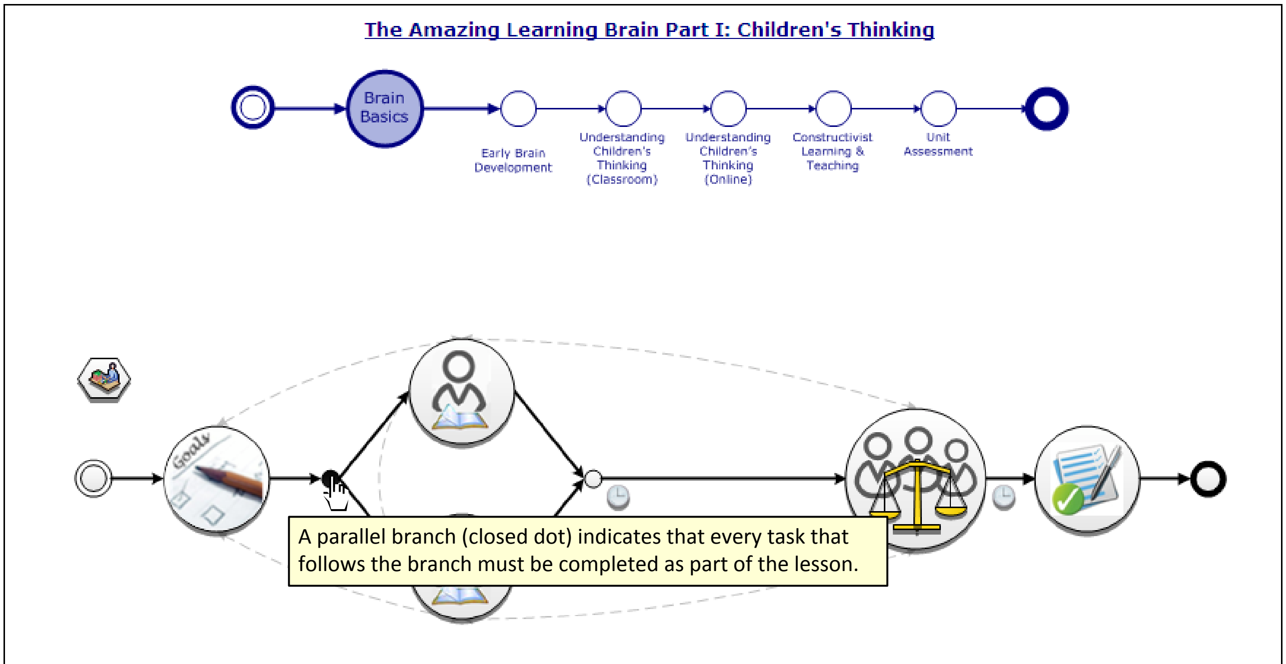
***Screenshot 2*. HAL Online Demonstration Site.** Opens in a new window and shows the Moodle course environment that students see. The lesson for 'Brain Basics' is shown.



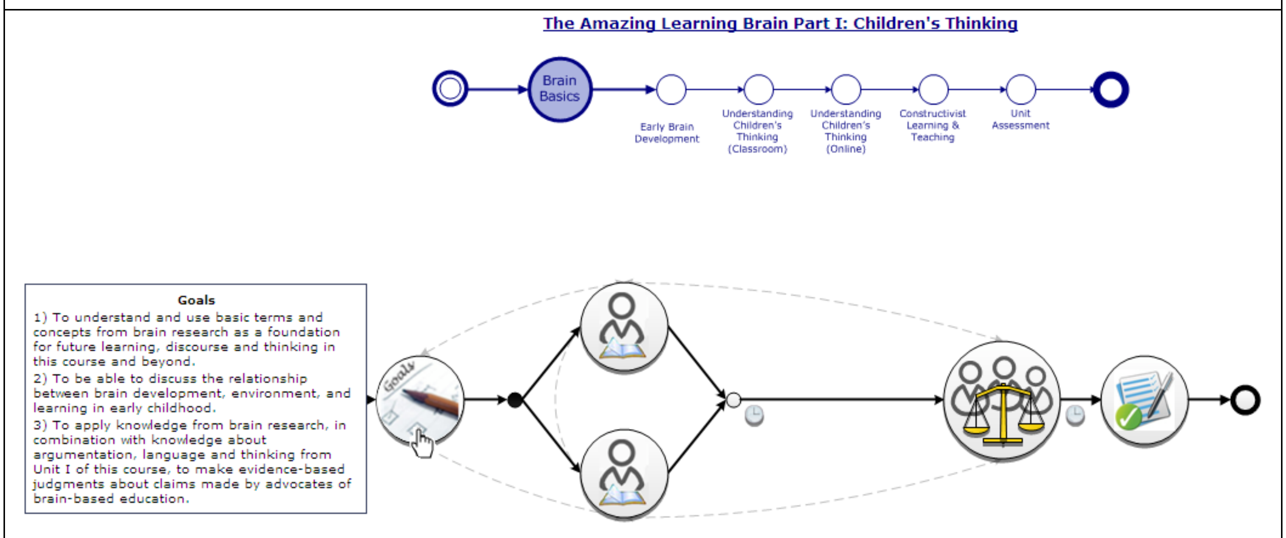
***Screenshot 3.* Lesson or *macro*-workflow.** Illustrates Tufte's principle of micro-macro readings. The visual detail of each icon provides information about the task it represents – e.g., an individual reads a textbook. Zooming out to see the collection of tasks provides visual information about the lesson – e.g., there are goals, students have two assigned readings from a textbook(s), a group does an analysis activity, and there is assessment information.



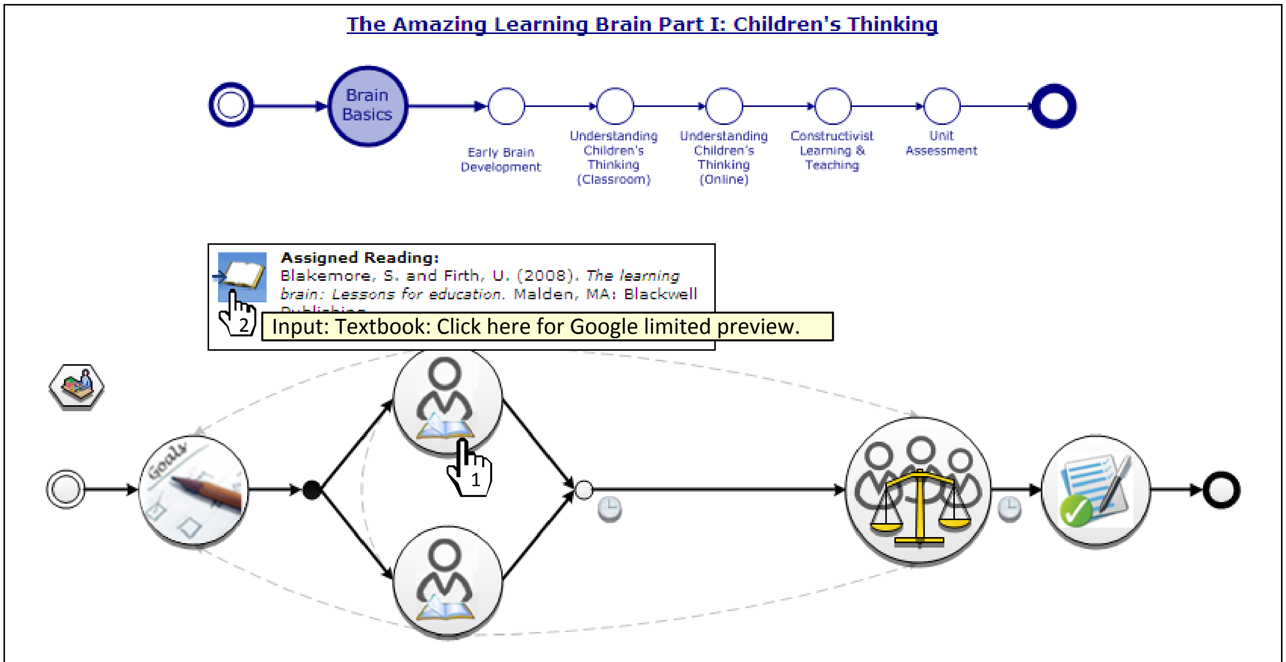
***Screenshot 4.* Workflow Legend.** Provides definitions for all icons in the workflow.



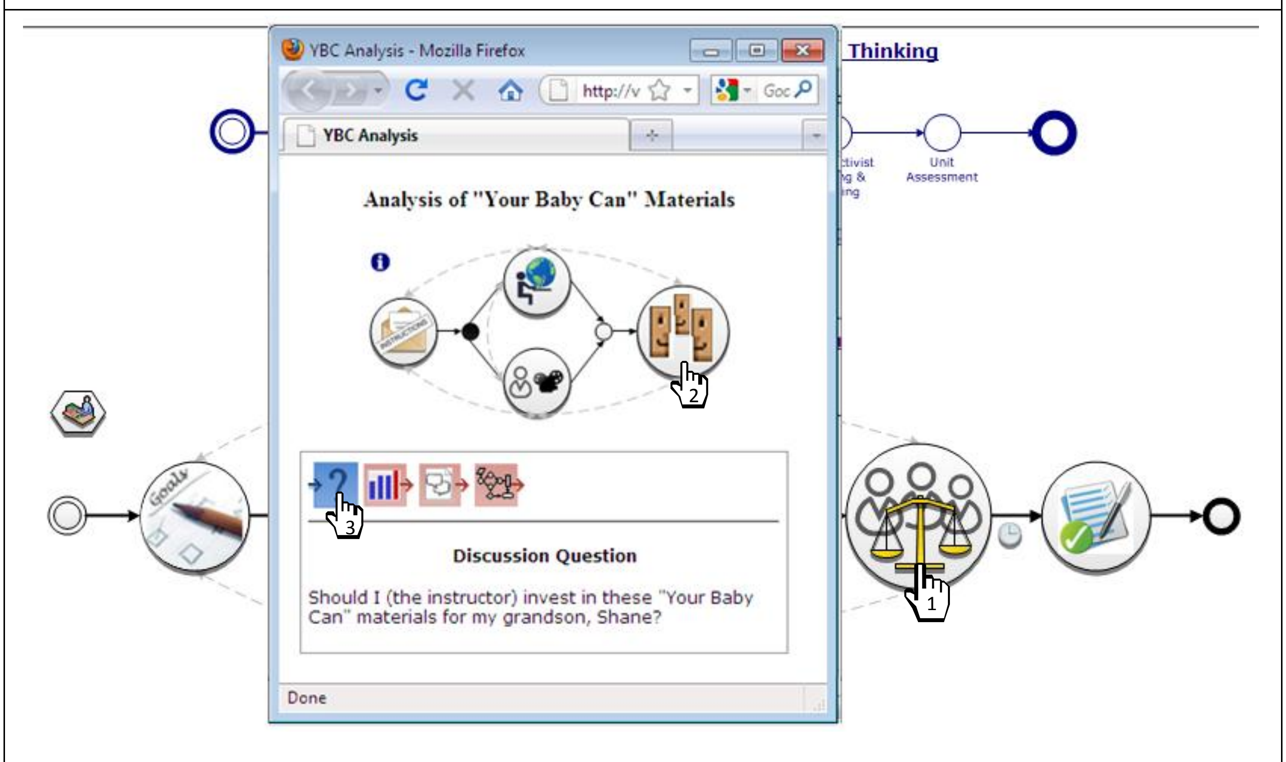
Screenshot 5. **A Standard Tooltip.** Provides another source of information about the workflow. When a user hovers the cursor tip over elements of the workflow a standard web tooltip opens with information about the element or instructions on how to expand the element to access more information. In this case, the closed dot is a parallel branch that directs lesson flow.



Screenshot 6. **Lesson Goals.** Appear in a "smart tooltip" – a pop-up box – when the cursor tip is placed in the goals icon. The box disappears when the cursor is moved out of the circular icon.

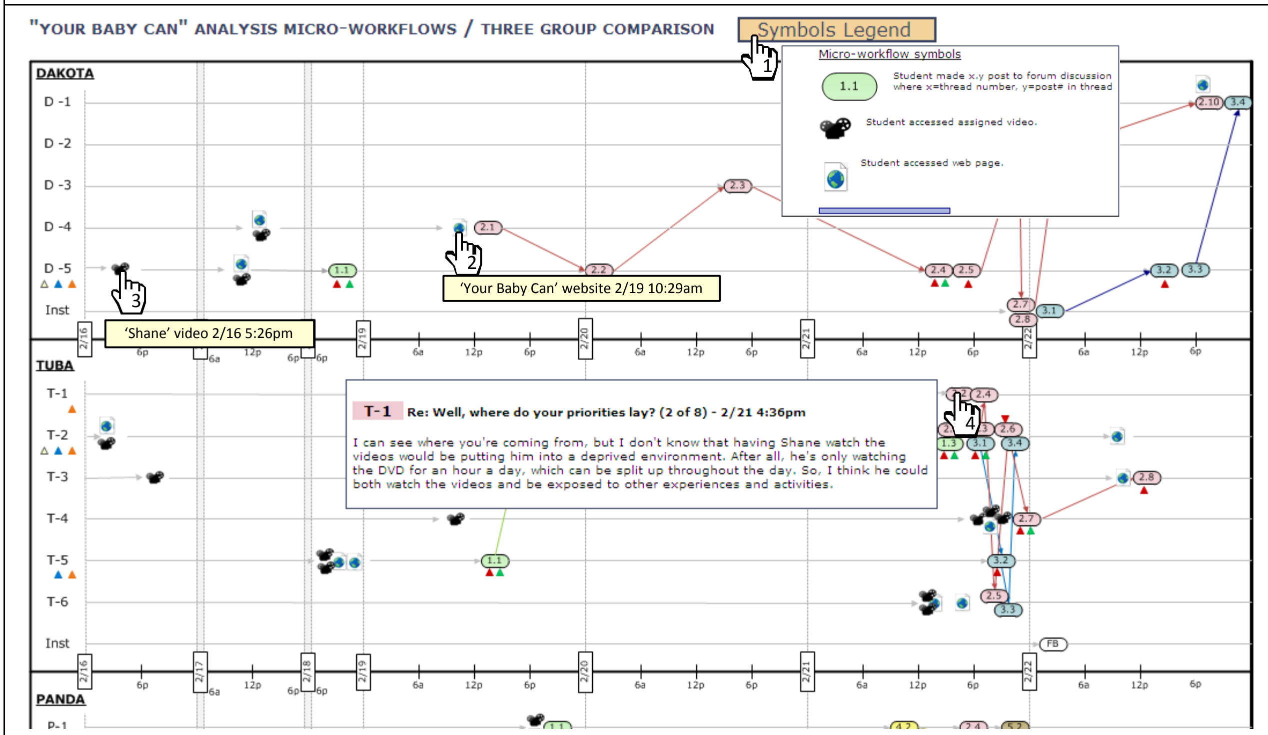


Screenshot 7. **Hierarchy of displayed information.** (1) Place the cursor on the “individual reads textbook’ icon and a smart tooltip pops up and displays information about the reading assignment. The display includes an input icon. (2) When the cursor tip is placed on the icon, instructions are provided on how to access a copy of the reading. Clicking on the icon would open the Google limited preview in a new window.

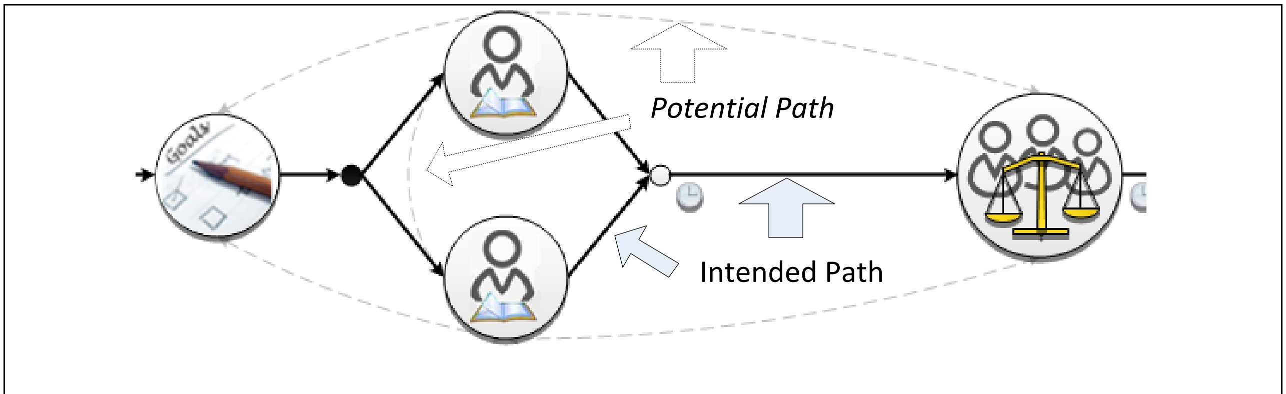


Screenshot 8. **Sub-workflow** (1) Click on the “small group analysis icon to open the sub-

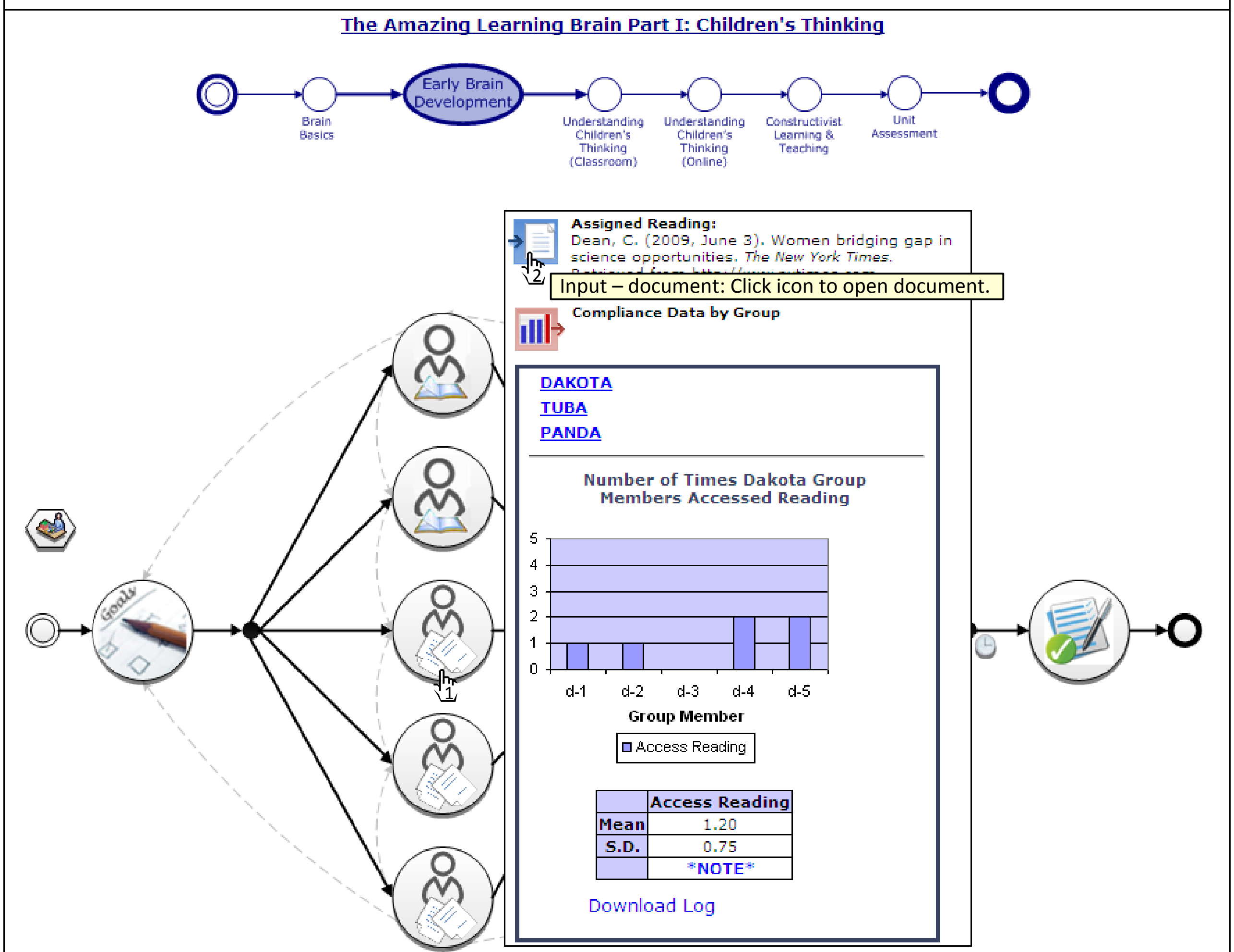
workflow in a new window. The display includes a small workflow visualization and an information window that changes depending on where the cursor is placed. (2) When the cursor tip is placed on the discussion icon, the information window displays four icons. From left to right: the discussion question (which is displayed by default), compliance data for the discussion, a transcript of the discussion, and the micro-workflow of the discussion. (3) Placing the cursor tip on any of these icons displays the information associated with the icon or a link to more information.



Screenshot 9. **Micro-workflow.** Displays information about when individual students access resources and make discussion posts. Data is plotted on a timeline scaled for the week-long lesson (periods on inactivity are collapsed in grey bands) Students are arranged in groups so that group interaction (in the discussion) can be plotted. Points of interest: (1) A symbol legend defines the icons used in the visualization. (2) When the cursor tip is placed on the web page icon, the date and time of access are displayed. (3) Same thing with the video icon. (4) Mousing over a post icon displays the date and time, position of post in its respective thread, and content of the post in a smart tooltip pop-up.

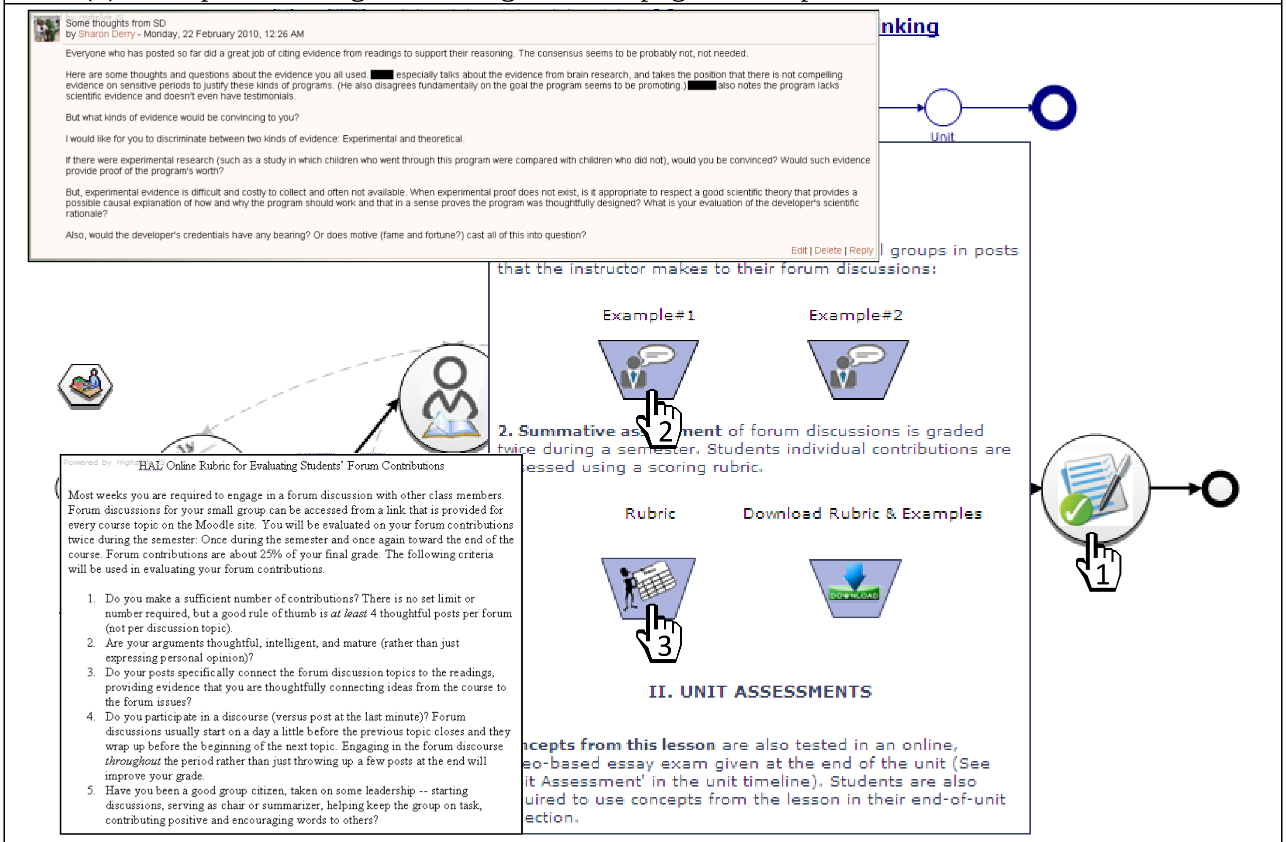


Screenshot 10. **Flow of lesson.** Lessons are designed to have a particular flow of tasks; this is designated in a workflow visualization with solid lines. However, in educational workflows a student may start with a different task than intended and navigate through the lesson in unintended ways (potential paths designated with dashed lines). They may also revisit tasks over the course of a lesson and iteratively refine their understanding of lesson concepts.

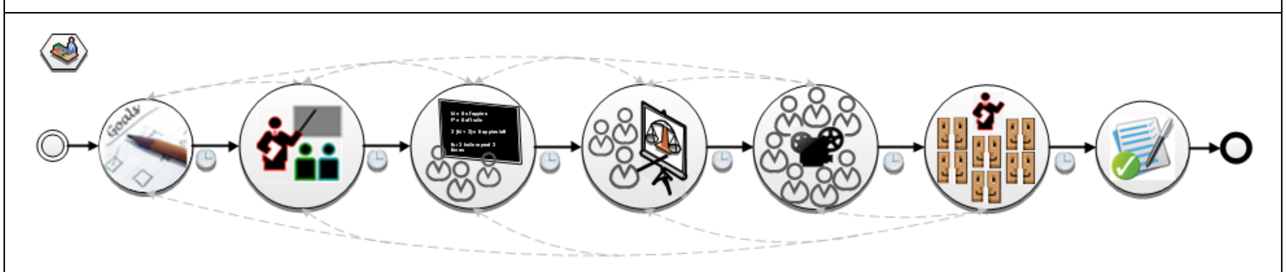


Screenshot 11. **Lesson workflow.** When a task is 'read document' (1), compliance data is

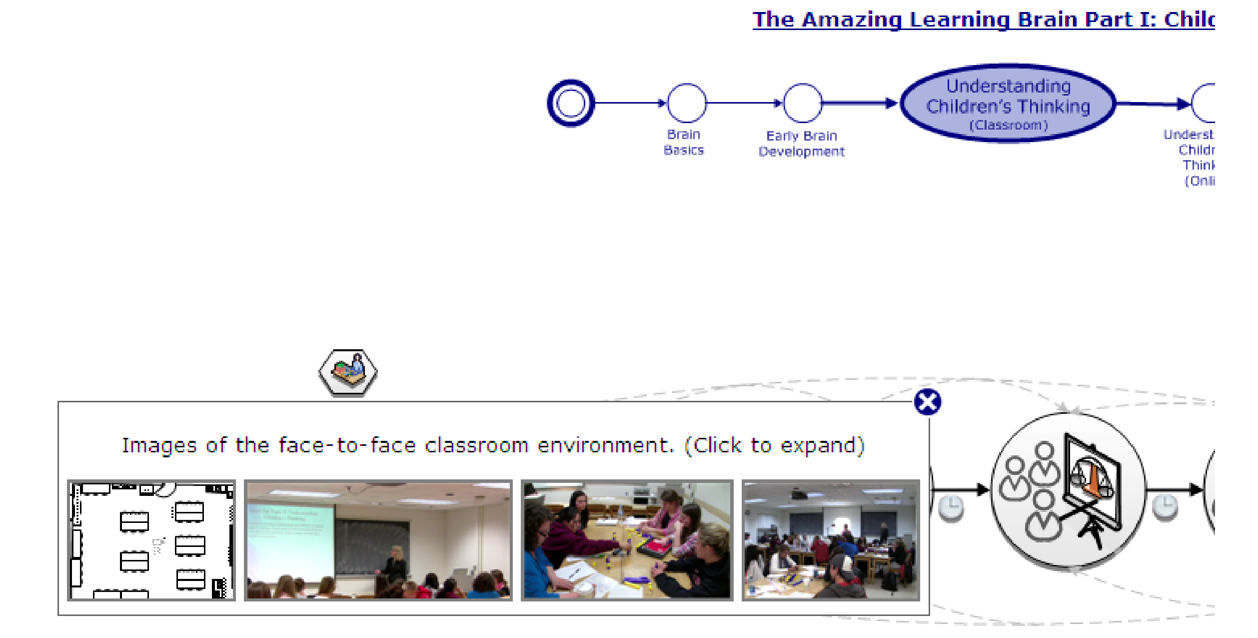
displayed immediately in the smart tooltip pop-up with links to each group. Clicking on the input icon (2) will open the assigned reading in a web page or as a pdf.



Screenshot 12. **Assessments.** (1) Placing cursor on assessment icon opens a smart tooltip pop-up that displays icons that open; examples of formative assessment, the rubric used to score forum discussions, and to download the rubric and examples of student discussions. (2) Clicking on and 'Example' icon expands an example of an instructor post in a group discussion that asks a question and points to what other groups are doing. (3) Clicking on the 'Rubric' icon opens the list of criteria that are used to grade forum discussions. The example and rubric pop-ups are movable and close when clicked on.



Screenshot 13. **Face-to-face classroom workflow.** Classroom lessons tend to be more linear because of time constraints and the instructor has more control over the lesson flow.



***Screenshot 14.* Workspace in the face-to-face classroom workflow.** Workspaces are described with diagrams (e.g., of the classroom or a seating chart) and pictures of different activities. Clicking the displayed thumbnails with expand the images to a larger size.

Appendix B

Interview Protocol for Researcher/Teacher Educator

The interview will be videotaped with a fixed camera.

The “Amazing Learning Brain” workflows will be used during the interview for demonstrations of workflow features and to illustrate the context of some questions.

Interviewees will be given:

- A handout of the current workflow icon library.
- Sheets of labels with multiple copies of all workflow icons
- Markers
- A poster sheet

Interviewer’s script:

I. Introduction

“The Workflow Representation methodology was designed to 1) facilitate sharing of learning interventions and 2) support research on the. During this interview I will ask you to wear the hats of both designer/teacher of a learning intervention and researcher.

We will begin with a task in which you will use sticky labels, markers, and chart paper to construct the workflow of an intervention on which you would conduct a research study. I will talk you through the basic steps of building a workflow, including organizing the flow of tasks [including the branching and merging of multi-tasks] and connecting them, adding information about the resources used with each task, the roles of participants during a task, and identifying the kind of data that will be collected from each task.

I will then use your constructed workflows and the website workflow representations of the “Amazing Learning Brain” unit to ask you questions about the current design of the workflow representations in terms of 1) the way information and data is displayed, and how it is revealed to the user as s/he mouses over or clicks on icons or links, 2) how it facilitates sharing of interventions [i.e., what are the strengths of the design; what are the limitations], and 3) how workflow representations would support the research questions you would ask about the interventions you design and implement [i.e., what are useful features, what is missing, what would you add, etc.]

Do you have any questions or comments before we begin?”

II. Guiding the Building of a Workflow

“You have before you a sheet of poster paper, markers, and sheets of labels that include all of the icons that I have designed to build workflow representations of instructional interventions. You will use these materials to build a workflow using the basic methodology I have used to build the “Amazing Learning Brain” workflows. I will break this activity into several tasks.

<u>Task 1</u>: Think for a moment of an instructional intervention that you have designed and used in the past [or one that you would like to use in the future] whose implementation you have [would like to] study. On your poster sheet write a brief description of the intervention and a list of the research questions you asked about it [Note: These might be questions that spanned several interventions or implementations.]

Do you have any questions?

[Wait for participants to complete the task.]

<u>Task 2</u>: Think about the tasks that make up your intervention in terms of what is being done, by whom [in what kind of group configuration], using what resources, producing what output, and taking how long to complete. Think about the order the tasks will be done in, if there are some tasks that are being done concurrently, or if there are some tasks for which the order of completion does not matter.

You will start building the workflow of your intervention by organizing the tasks in terms of the order that they will be done. We will use the "Brain Basics" lesson workflow as a model. [Show the "Brain Basics" workflow on the projector screen] For example, begin with a 'Start' icon, place a 'Workspace' icon above the 'Start' icon, if you have concurrent tasks they will be displayed vertically [point to concurrent task representation], and finish with 'Stop' icon. Use sticky labels of tasks to build the initial workflow. Find icon stickers that closely match your tasks and lay them out in the order that the tasks will be done. Leave plenty of room between the tasks [because we will be adding additional information to our workflows]. I suggest that you wait to peel the backing off the labels until you're certain of the order of tasks. If there is not an icon sticker that matches your task, choose a blank icon sticker [small for task done by an individual and large for a group task] and write a brief identifier for the task. Arrange concurrent tasks, [or tasks whose order of completion does not matter], one above the other. When you are comfortable with the order of the tasks, stick them to the poster paper.

Do you have any questions?

[Wait for participants to complete the task.]

<u>Task 3</u>: "Next you will add connectors that show the flow from one task [or concurrent tasks] to the next. Use a marker to draw arrowed lines from the 'Start' icon to the first task and continue to draw arrows to each successive task. If you have concurrent or unordered tasks you will need to draw a small circle to represent a branch immediately before the task icons [Point to branch in "Brain Basics" workflow.] If all of the tasks need to be done by the student, draw a filled circle; if the student has to choose one from two (or more) tasks, draw an open circle. From that drawn circle, draw arrowed lines to all of the concurrent tasks. The workflow must merge to a point [Point to merge in "Brain Basics" workflow.] after the task representations. Draw a small circle to represent this merge. If the workflow cannot continue until all concurrent tasks are completed, draw a filled circle, otherwise draw an open circle. I have found that I most often use open

circles here [Explain why.] Continue to draw arrowed lines to connect all of the task icons; finish with the ‘Stop’ icon.”

[Wait for participants to complete the task.]

Task 4: “Next to each task icon write a very brief description specific to your intervention task. [Show example of description in “Your Baby Can” sub-workflow.] Also write the amount of time you expect the activity to take. Write a brief description of the workspace next to the Workspace icon [Show this in “Brain Basics” workflow].”

[Wait for participants to complete the task.]

Task 5: “You will now add inputs to each task. Choose an input sticker that displays an appropriate input icon; for example, if the task is to read an assigned textbook chapter, choose a sticker with a blue textbook input icon [Show example in “Brain Basics” workflow]. On the sticker briefly identify the resource”.

[Wait for participants to complete the task.]

Task 6: “Next to each task - if not obvious - jot a brief description of the roles of the participants (student, group, instructor).”

[Wait for participants to complete the task.]

Task 7: “Next we want to identify all the places that you expect to be able to collect data about your intervention [in order to help answer your research questions]. If doing a task generates an artifact that can be collected or logged – e.g., video of a class meeting, written assignments, online discussion forum, online dropbox, etc - use an output sticker that displays an appropriate output icon; for example if students are accessing a video clip and you want to know who and how many times, choose a sticker with a red compliance chart icon [Show example of description in “Your Baby Can” sub-workflow.]”

Interview Questions

III. Introduce Questions

Now that you have completed a model of a workflow representation, I am going to ask you questions that you may use this experience and your experience viewing the “Amazing Learning Brain” workflow representations, as well as your experience as educators and researchers, to answer.

I will start with questions about the current user interface and library of workflow icons as used to create the “Amazing Learning Brain” workflow representations, and then ask about how the workflow representation and the methodology would be useful to you as an educational designer and researcher, and what limitations you see in the current version. I will finish with questions about next steps for evolving the tool/methodology, and for my own research.

<u>User Interface</u>

1. My intent with the macro-workflows – the visual representation you see when you open the workflow website - is that you would be able to develop an initial understanding of the goals, tasks, personnel groupings, assessments, etc. of the represented intervention. What is/was your initial impression when you look(ed) at the prototype workflow representation(s)?
    a. What is particularly helpful about the design?
    b. What needs to be clearer?
2. I have developed a collection of icons in a library that are intended to describe tasks, inputs, outputs, assessments, etc, in a broad range of courses. What is your opinion of the current collection of icons?
    a. Are they adequate to describe your tasks, inputs, outputs, roles, etc.?
    b. If not, what icons are missing?
    c. Are there more icons than you would ever use? If so, which would you not include in the library?
    d. Does the visual design of icons provide cues about a task with respect to what is to be done, by whom, using what resources? Please give an example.
3. What do you think about the way that information/data automatically pops up in a tooltip (or disappears) when the user mouses over a task icon helpful or a nuisance?
    a. What if that information were displayed in a fixed box that you had to manually close; would that be better than the current design? [If so,] why?
    b. When a tooltip "pops up" do you intuitively move the cursor into the tooltip area and mouse over or click on icons [Demonstrate with "Brain Basics"] with the expectation that additional information will be made available? If not, how could the visual display within a tooltip be changed so as to provide a visual cue for you?
4. Sub-workflows are expansions of certain tasks that are themselves made up of two or more tasks. [For example, show "Your Baby Can" Analysis] What do you think of the sub-workflows in terms of:
    a. Size of the display window?
        i. Do you realize the browser window can be resized and moved?
        ii. Are you inclined to experiment with the user interface?
    b. Display of information?
    c. Navigation; do you understand how to move the cursor about within the sub-workflow to access different information)? [Demonstrate with the "Your Baby Can" analysis.]
5. What is your opinion of the current levels of information accessibility/display? [For example; to access a micro-workflow you have to follow the path such as: workflow > analysis icon > sub-workflow > discussion icon > micro-workflow output icon > hyperlink]
    a. Why do you say that?
    b. What would be a more useful way to structure the information?

Instructional Design and Sharing

1. Think about a tool that you could use to build workflow representations? What features would you want the tool to have? [Think about your earlier experience of building a workflow representation of a lesson.]
    a. Would you be comfortable using a "drag-and-drop" type of tool to build workflows?
    b. Would a "build-your-own-icons" feature be necessary?
2. What would be advantageous about using this workflow representation methodology to build representations of interventions that you teach? What would be a limitation of the methodology?
3. What caveats would you need to include if you were going to use workflow representations (such I created for the "Amazing Learning Brain" unit) to share interventions?

Research

1. In what ways would the workflow representation methodology facilitate the research that you do? [Think about your earlier experience of building a workflow representation of a lesson.]
    a. What kinds of research tasks could be supported with workflow representations
    b. What would make it a more useful research tool?
2. Thinking about research on learning environments that you have done in the past, what research questions might you ask that the current workflow representation design would NOT inform? Can the existing design be modified to include this information/data? [If so] in what way?

- What comment(s) about the current workflow representations with respect to design of interventions and research would you like to make that I haven't asked about?

Next steps

- With respect to the VMC, what next steps need to be taken in developing workflow representations?
- What advice would you give me with respect to next steps in my own research?

Thank you for participating in this interview.