Adapting Workflow Technology to Design-Based Research: Development of a Method for Organizing the "Messiness" of Research in Technology-Rich Online Learning Environments

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Abstract: A fundamental challenge of design-based research is that there are many variables that affect success of a design. Designers collect large amounts of data, but limited time and resources make analysis difficult and conclusions uncertain. Workflow technology is utilized in business and applied science environments to automate work processes and reveal "know-how," often tacit in scientific processes, which facilitate multiple levels of reuse. We developed a method for representing activity in an experimental online course as workflow expressions. Bielaczyc's (2006) Social Infrastructure Framework (SIF) is utilized to identify important variables, and *comprehensive data mining* (CDM) techniques are used to recover data from course session modules and activity logs. In this paper we review the literature related to our theoretical framework, describe the CDM-based methodology, and give an example of how we are using it to support design-based research within an online college course.

Introduction

This contribution reports a new design research methodology based on workflow technology (Georgakopoulos, Hornick, and Sheth, 1995; Ludäscher et al., 2005) and the Social Infrastructure Framework (SIF) (Bielaczyc, 2006) that is especially appropriate for online learning environments. The context for our work is HAL Online, an innovative experimental section of "Human Abilities and Learning," a required course for teacher education and other education-oriented majors offered through the Educational Psychology Department at the University of Wisconsin-Madison. HAL Online includes reading assignments, online exams, and meets in person occasionally, but the primary instructional method is online argumentative discourse in small group discussion forums. Small groups comprise 5-7 students who are grouped by the instructional staff based on their similar majors and career interests and who work as a team throughout the semester. There are about 5 groups and 30 students in each course offering. The broad goal for HAL Online students is to acquire foundational understanding of human learning and thinking that is grounded in current research and theory from cognitive science, socio-cultural theory, and neuroscience. Students must demonstrate such understanding by using course ideas to: A. construct and justify well-formed arguments about a range of important topics; B. articulate and evaluate the reasoning and arguments of others, including peers and school children; C. participate effectively in argumentative small-group discourse online; and D. work collaboratively to design, justify, and critique instruction that aims to promote good thinking in areas related to their disciplinary majors.

The course is divided into 4 units: Language and Reasoning; Brain-Based Education; The Mathematical Basis of Reasoning; and Instructional Design (a small-group project). Each unit comprises 3 or 4 interrelated modules, each lasting one week. There is a required face-to-face (FTF) class for each unit. In FTF classes students hear lectures, discuss readings, solve and discuss reasoning tasks with their group, and build community and rapport with their peers. In a typical week students are given a reading assignment from a text that they complete over a 2-day period. During this period they may also participate in a warmup activity online which often involves viewing a video. Following this individual preparation they are required to go online and participate with their small groups in a discussion activity. A typical discussion activity is "Brain Gym," part of the Brain-Based Education unit, in which students are asked to play the roles of parents and educators trying to decide whether either of two brain-based curriculum proposals should be offered by their school. Another is "Math Wars" in the mathematical reasoning unit, a discussion of whether a school should adopt a progressive mathematics curriculum and approach exemplified in videos viewed online.

In this paper we illustrate our proposed workflow methodology with "Adventures in Argument," a one-week module within the Language and Reasoning unit. In this activity students are required to observe and evaluate arguments made in the popular media about current issues in the news. For example, in one semester students evaluated arguments made in political debates. In a recent semester students evaluated arguments about different health reform bills. Students' participation in small-group discussions is graded in accordance with a rubric (see Table 1).

Table 1. Criteria for evaluating students' forum contributions

1. Do you make a sufficient number of contributions? There is no set limit or number required, but a good rule of thumb is *at least* 4 thoughtful posts per forum (not per discussion topic).
2. Are your arguments thoughtful, intelligent, mature, and justified with reasons and evidence (rather than just expressing personal opinion)?
3. Do your posts specifically connect the forum discussion topics to the readings, providing evidence that you are thoughtfully connecting ideas from the course to the forum issues?
4. Do you participate in a discourse (versus post at the last minute)? Forum discussions usually start on a day a little before the previous topic closes and they wrap up before the beginning of the next topic. Engaging in the forum discourse *throughout* the period rather than just throwing up a few posts at the end will improve your grade.
5. Have you been a good group citizen, taken on some leadership -- starting discussions, serving as chair or summarizer, helping keep the group on task, contributing positive and encouraging words to others?

At the end of each unit each student is required to submit a reflection on what they have experienced and learned in that unit. These submissions are "published" through the blog facility provided in the Moodle course management system (CMS) through which we offer the course online. At the end of each unit students individually complete an online quiz assessing their mastery of the material in the unit. A typical quiz question provides students with a link to a video and asks the students to analyze the video in some way. For example, in the mathematical reasoning unit, a video of a child solving a mathematical task is provided and students are asked to use course ideas to describe and analyze the child's reasoning and problem solving strategies.

Design-Based Research (DBR)

Design-based research is grounded in the systematic design and study of instructional strategies and tools in authentic contexts (Barab and Squire, 2004); as such, there is no one accepted definition or methodology. The Design-Based Research Group (2003, p. 5) identifies characteristics of "good" design-based research. The critical characteristic is that the central goals of designing learning environments and developing theories or "proto-theories" of learning are intertwined. Development and research takes place through continuous cycles of design, enactment, analysis, and redesign, and research must account for how designs function in authentic settings – not only in terms of success or failure, but also in terms of understanding the learning issues involved.

One purpose of our research is to improve the effectiveness of our course through an iterative process in which we make deliberate design changes. Another purpose is to assess the effects of design changes that are made out of necessity, often due to constraints over which the instructional staff has little control. For example, when the course is taught in summer it must be squeezed into a four-week intensive time period, which is very different from the full semester course that is stretched out over a 16-week period. Because the primary instructional method is online argumentative discourse in small groups, a third purpose of our research is to propose, test, and develop "proto-theories" about how small groups in online environments collaborate to produce successful outcomes.

Collins, Joseph, and Bielaczyc (2004) describe challenges that a design-research team faces when implementing design experiments. Foremost is that research is usually conducted in the "blooming, buzzing confusion" of classroom learning environments (Brown, 1992). There are many variables that influence the success of a design, and many of those variables cannot be controlled (Collins, Joseph, & Bielaczyc, 2004, p. 19). Furthermore, each variable is part of a systemic whole; it is impossible to change one aspect of the system without creating perturbations in others (Brown, 1992). Yet it is important to identify the critical variables of a design and how they fit and work together in practice (Collins, Joseph, & Bielaczyc, 2004, p. 34). One needs a well developed profile of an implementation in order to analyze a design in terms of its key elements and their interactions, and to determine how exactly one design differs from another in ways that might impact outcome. Because of the number of variables to account for, design researchers usually end up collecting large amounts of data, more data than they have time or resources to analyze (Brown, 1992; Collins, Joseph, & Bielaczyc, 2004, p. 19). To ensure that design researchers maximize their use of the collected data, analytical procedures that organize and document data in an easily accessible format that facilitates more efficient, deeper analyses are needed.

Barron (2007, p. 178) discusses the emergence and value of *intermediate representations* as a response to this need. Focusing her discussion on video research, she argues that intermediate representations are important for identifying *what to analyze* and for *understanding patterns within and across* segments of video. 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 characteristic of DBR; that the goal of developing sharable, adaptable learning interventions of practical use to practitioners is intertwined with the goal of developing theories or "proto-theories" of learning (Collins, 1992). Inspired by a suggestion from Rutgers colleague Grace Agnew (personal communication, 2007), we explored the potential of workflow technology to provide such representations.

Workflow Technology

The core features of workflow technology – organizing the data, tools, participants, activities, and flow of a system – are well suited to the challenges of design-based-research (DBR). DBR researchers must attend to a large number and range of variables and their interrelationships, and they must control or at least be aware of the variable manipulations that occur either intentionally or unintentionally, during each iteration of the design research process. Workflow technology is especially useful in online learning environments such as ours because many variable values and their relationships *can be recovered post hoc* from activity logs and other data created in the online course management system (CMS). Workflow expressions derived from such data can provide diagrammatic, annotated representations of a targeted part of a course as a system. Strauss

In the following sections we will review the literature that contributed to the theoretical framework for our workflow expressions approach and provide an example of how the visual models are used to support analysis in design-based research.

Theoretical Framework

Core concepts of our workflow expressions model come from the Social Infrastructure Framework (Bielaczyc, 2006), the literature on business and applied science workflows (Georgakopoulos, Hornick, and Sheth, 1995; Ludäscher et al., 2005), and adaptation of a comprehensive data mining (CDM) model developed by the Collaborative Technology Research Group (CTRG) at the University of Colorado-Boulder (Rembert, 2006).

The Social Infrastructure Framework (SIF)

The SIF identifies critical design elements to be aware of and accounted for when designing socio-techno learning environments, and articulates them in terms of four dimensions (Bielaczyc, 2006). These are summarized in Table 2:

Table 2. Critical design elements of socio-techno learning environments.

Dimension	Characteristics
Cultural beliefs	Cultural beliefs are not *designed* per se but cultivated over time, and influence such things as: how learning and knowledge are conceptualized, goals, how identities of students are shaped, how the identity of the teacher is understood, and how technology use is viewed.
Practices	Concerns the ways in which teachers and students engage in activities with tools, how students work on activities, how groupings of students are organized, what roles students play within groups, modes of interaction supported or constrained within and between groupings, and the role the teacher plays.
Socio-techno-spatial relations	Concerns the organization of physical space and technology workspaces as they relate to teacher and student interactions. Considerations include the physical organization of classrooms, how groups incorporate technology, the affordances and constraints of the technology, how pervasive technology use is in the intervention, how access is provided
Interactions 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 to consider include issues of authenticity: How is knowledge brought in from and extended to the outside world?

Consideration of what variables can capture the characteristics of these dimensions informs the design of data collection from online modules, highlights what should be mined from available activity logs, and influences the look of a resulting workflow expression by identifying what information needs to be represented

Workflows in Business and Science

Workflow is a concept closely related to the design, or reengineering, of business and information processes (Ludäscher et al., 2005). In a broad and multi-leveled sense a workflow expression is the diagrammatic result of "capturing" the workings of a system from beginning to end.

Within the literature two broad versions of a standard definition of workflow emerge: business and scientific. Georgakopoulos, Hornick, and Sheth, (1995) describe a *business-oriented* workflow as a collection of tasks organized to accomplish some business process, performed by one or more software systems, one or a team of humans, or a combination of these. A workflow defines the order of task invocation, task synchronization, and dataflow. S*cientific workflows* are valuable knowledge assets in their own right because they are graphical representations of scientific "know-how" that is often tacit. A key feature in the development of scientific workflows is the notion of reuse (De Roure, Goble, and Stevens, 2008). Reuse can occur at multiple levels. With different parameters and data, fragments and patterns of workflows 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.

Both business and scientific workflow expressions attempt to define processes of a system in terms of the tasks performed, order, resources consumed and produced, and relationships between person and machine. Both account for control of events and flow of data. However, when analyzing the underlying principles of the approaches, Ludäscher et al. (2005) found a focus on *control flow patterns* and *events* – what was done, and in what order – in business-oriented systems, while scientific workflow systems tended to have execution models that were more *dataflow-oriented* – interest in how data gets passed through, transformed, and used by the system (p. 1046).

The concepts of reuse, control flow, and data flow are all important to account for in an educational workflow model; they facilitate sharing and analysis of adaptable interventions. However, the unpredictability of educational interventions noted by Brown (1992) suggests that educational workflows cannot be preprogrammed in the way that many business or scientific-oriented workflows are (e.g., loan applications or mineral identification systems). The important functions of educational workflows, then, include capturing and representing: 1) the intended, adaptable aspects of interventions that can be shared and reused across diverse educational and research settings; and 2) the actual and detailed data flow within interventions, which supports scientific analysis. This suggests two kinds of educational workflows; the former, which we will call *macro-flows*, may be roughly equated with educational *macro-scripts*– general pedagogical models, often representing intentions, that aim to create learning situations in which productive interactions and outcomes will hopefully occur (Dillenbourg and Hong, 2008). The latter are *micro-flows*, which are like "micro-scripts," although they may emerge during practice and are determined post-hoc. Micro-flows represent more detailed models of actual individual and group activity. In online environments, data for both types of workflow representations can be mined post hoc from activity logs and other data found in the course management system (CMS). We hypothesized that both would be useful in design-based research.

Comprehensive Workflow Mining

Much of the literature on workflow modeling focuses on the use of Petri-Nets to automate and analyze business processes (e.g. van der Aalst, and van Hee, 2004), a highly structured, mathematics-based methodology that describes processes in terms of weighted nodal relationships among places and transitions. This workflow method's focus on control flow makes it 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 comprehensive 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 (Rembert, 2006). Briefly, the primary perspectives focused on by this modeling methodology include: the **functional** – *what* tasks or activity takes place; the **control flow** – *when* tasks are done; the **informational** – *which* data are processed and the *data flow* of the process; the **resource** or **organizational** – *who* or *what* performs a task; and the **operational** or **application** perspective – *how* a task gets done.

The ICN workflow modeling language has a mathematical and graphical representation; for the purpose of the present paper we focus only on the graphical elements of representation. These elements are shown and described in Table 3:

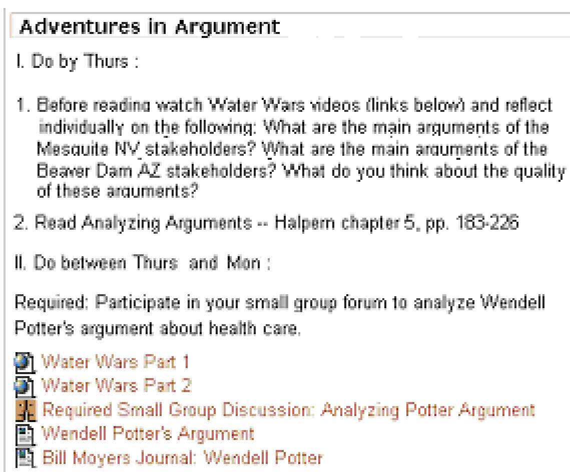
Table 3. Graphical elements of the ICN workflow modeling language.

	Tasks (represented by labeled circles) are a unit of work carried out by one or more people.		*Data repositories* (represented by labeled squares) have production/consumption relationships with tasks - they provide data that is consumed by a task or collect and hold data produced by a task.
	Roles (rounded rectangles) can represent individuals or groups, 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* (hexagon), to be completed, then that task might be accomplished by any *application instance* (monitor).		There are four *control tasks*; two branch tasks – parallel (closed circle) and conditional (open), and two join tasks – synchronization (closed circle) and merge (open).

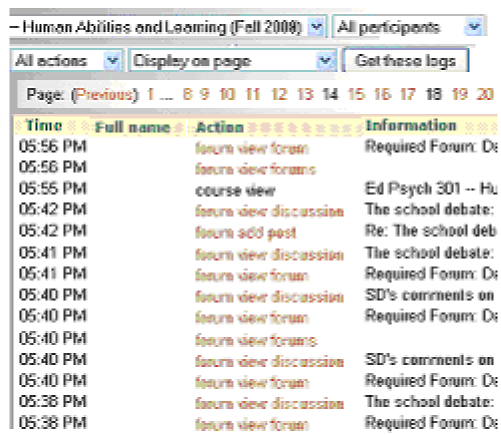
Example of Analysis using CDM-based Workflow Expressions

Mining Data and Constructing Workflow Expressions from Adventures in Argument

The Moodle session module shown in Figure 1(a) provides information to students about what activities to do, in what order, and provides links to online resources and tools that are needed for activities. (The link to the discussion provides further instructions to students, and hence workflow information, that is not shown here).



(a)



(b)

Figure 1. HAL Online module seen by students (left) and partial activity log (right).

Such information is used to construct the *macro-workflow* expression shown in Figure 2. Each activity is represented in a circle and the flow from one activity to the next is shown with arrows. Closed dots before the 'View Video' activities indicate that both activities must be done, but order doesn't matter. Open dots after indicate that activity can proceed even if a student only views, for example, one of the two videos. Percentages by each circle indicate the level of compliance for two groups that were examined in this example. These data were "discovered" by mining the activity logs (see Figure 1(b)). Information about tools, roles and data repositories are represented using ICN graphical elements (Table 3). We added new icons for special data repositories unique to educational work: a book for textbook-type information, and a silhouette for representing students' activated prior knowledge.

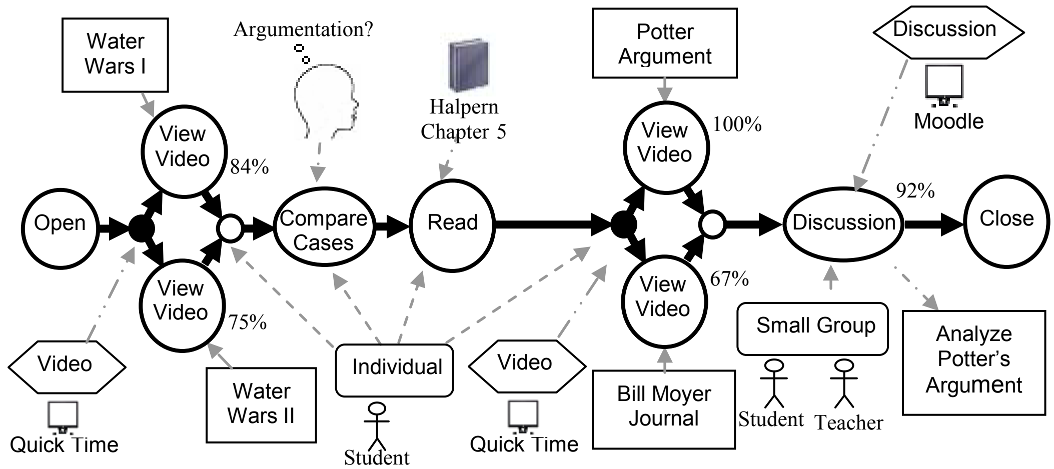


Figure 2. Macro-workflow expression for "Adventures in Argument".

Figure 3 illustrates how logs specific to Moodle tools (i.e., the discussion tool) and resources (i.e., videos) were used to construct *micro-workflows* for the discussion activity (part of the macro-flow) for students in two contrasting groups in our course. Micro-flows were organized in two musical-type "scores" above and below a master timeline that allowed us to see the flow of data for individual students in each group as they engaged in the discussion activity. In the diagrams, small open squares indicate when students viewed videos. The numbers inside the circles indicate thread number (left) and post-in-thread (right). Closed squares on the circles indicate that the post connects to a video or the assigned reading (which one can be seen specifically in the discussion log).

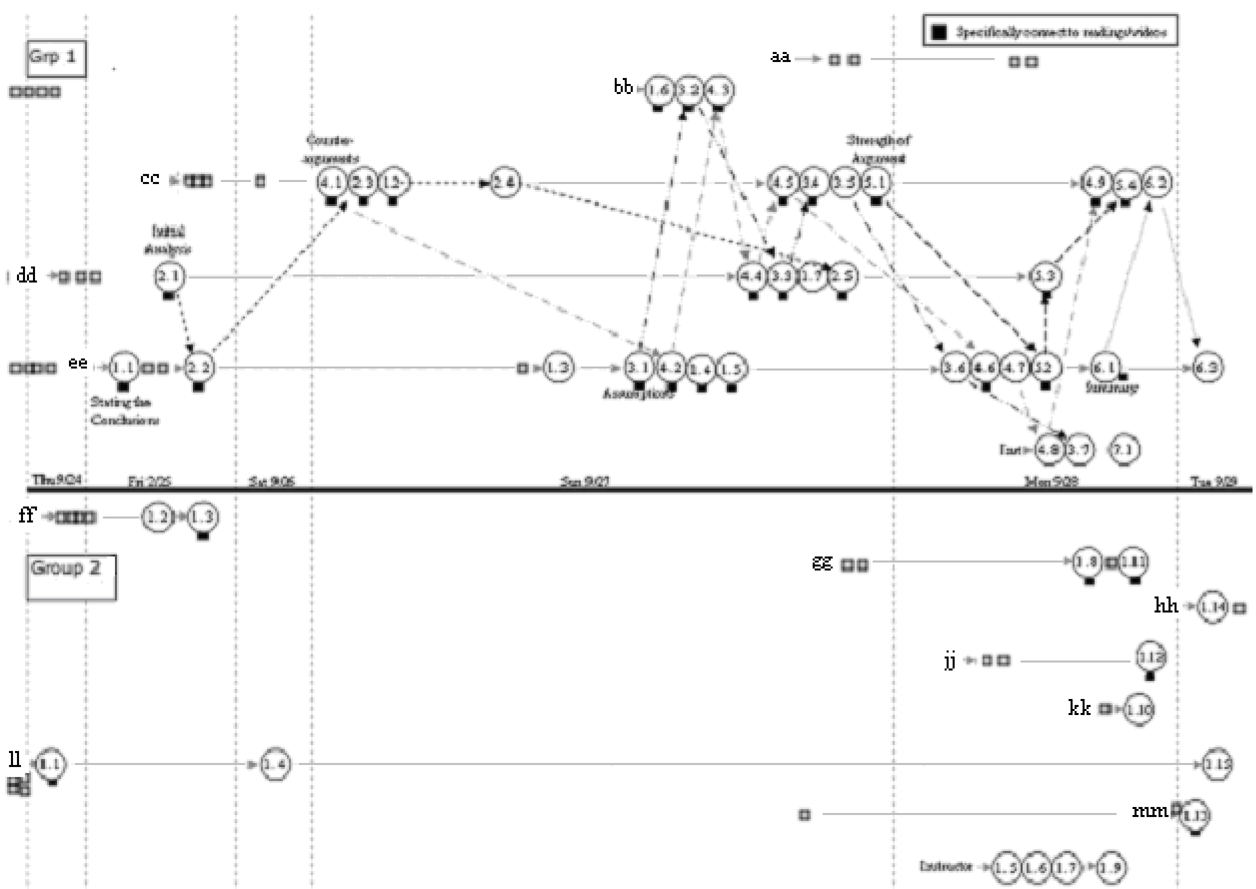


Figure 3. "Adventures in Arguments" micro-workflow expression for forum discussion of two groups.

Analysis

When analyzed by the instructional development team, both the macro- and micro-flow representations helped the research team generate many ideas regarding how well the Adventures in Argument module worked and in suggesting design changes for the next iteration. Even a cursory glance at the micro-workflows for the two groups (Figure 3) revealed stark differences in two groups. Group 1 generated a greater number of threads, postings, made more references to course readings and videos, and referenced one another's postings. Three different members started threads over the course of the discussion. By comparison, Group 2's postings were contained in one thread, postings were disconnected, no student posted more than three times, and four members made only one post. A closer examination shows that most members of Group 1 accessed *all* of the supporting videos early and often and even re-viewed certain videos during the discussion forum. In contrast, only members of Group 2 viewed all four videos before beginning the forum discussion; the majority of members viewed *some* videos right before making their posting. (In light of this, the compliance statistics in the macro-workflow are a little misleading; Group 1 actually had 100% compliance viewing the videos where Group 2's overall compliance was less than average for the class.) As well as Group 1 appears to do in comparison to Group 2, there is room for improvement. One member (OB) viewed the videos very late in the work process and did not participate in the discussion. In her reflection on the experience with the unit she reported that she had trouble viewing the videos and felt she was too late to make a contribution to the discussion by the time she fixed the problem.

The interpretive power of workflows is illustrated in reflections by the professor-researcher in charge of the course, who made the following observation:

> "I noticed some things that are possibly important. One thing was the similarity of Group 1 to a strong group in a study of five online groups that Mary and I did awhile back. The strongest group in that study had a strong leader who organized the discussion space, breaking the discussion down into sub-topics, starting some topics in a certain direction, sometimes giving particular assignments. In Group 1, CC takes a leadership role and does something similar that turns out to be important: He wrote *'I would propose that we start a separate thread for each of the main areas of analyzing the argument, such as conclusion(s), premises and omitted premises, counterarguments, assumptions, etc. I have started one on Conclusions. This organization will help us get a lot of material in an organized way which will hopefully make it easier to summarize in a couple of days.'* Also, Group 1 was far from perfect; there were non-participants. Students who were left out expressed frustration in their blogs with their inability to interact with the technology. These "weaker" students seem intellectually capable, but the technology may be putting them on overload."

Additional analysis of the macro-workflow expression (Figure 2) revealed that there were two activities – comparing cases and reading the text chapter – for which we could not verify compliance. Both activities relied to some extent on data repositories that were located outside the Moodle logging system. Students' compliance with reading of the text could be inferred from a closer examination of the students' postings, but the comparing cases activity, which had a theoretical rationale, could not be evaluated due to insufficient data. One role of the workflow expressions in DBR is to focus attention on design flaws that exist because an activity fails to generate log data that can be mined.

Conclusions

Our team was able to use the macro- and micro-flow expressions to guide us in making design changes to be implemented in the next iteration of our course. Examples under consideration include: 1) Create more explicit scaffolding on collaboration to be incorporated into the instructions for the discussion task – i.e., choose a leader, break discussion down into sub-topics, start discussion threads for each sub-topic, distribute tasks; 2) Emphasize in the discussion-task instructions that a post needs to include explicit references/connections to videos, readings, and/or other postings; 3) Mandate that students access resources early in the session (perhaps tying a grade to *when* they access or comment on resources). At the process level we decided to include logable tasks for all activities, e.g., write a brief summary of the case comparison in the warmup activity, or complete a short questionnaire about a reading.

Discussion

The example above illustrates how workflow expressions derived from data mined from the online session modules and activity logs of an online course can help facilitate the analysis of a complex environment by presenting visual representations that incorporate design variables of interest.

Both workflow expressions served a valuable purpose. The micro-workflow expression allowed us to see when and how individual students engaged in activities – their *control flow* – and how group members interacted with one another during collaborative activities, how they used course resources, and how they took up and used data created by one another – their *data flow*. The micro-workflow expressions facilitated hypothesis generation about success in group argumentative activities – that students need to organize their discussion space by breaking down arguments into sub-topics, starting some topics in a certain direction, and distributing tasks. This hypothesis amounts to a proto-theory about successful online argument as pedagogy, supporting a dual focus on theory-building and instructional design. Finally, micro-workflow expressions help identify problems that may be related to course tools or processes, e.g., inability to access videos. These kinds of insights also lead to instructional design changes.

Macro-workflow expressions provide a means for researchers to see all design elements of an intervention and their relationships to one another. This is important because it allows researchers some sense of control as they contemplate design changes. As Ann Brown (1992) pointed out, it is impossible to change one aspect of the system without creating perturbations in others. Macro-workflow expressions allow the researcher to focus design changes on specific areas of macro-flow while striving to monitor activities and achieve some level of control within others. An important goal of design-based research is to continually adapt an instructional design given new insights about the design, but an equally important question to ask is, "How much adaptation is taking place?" We believe the workflow expressions derived from course session modules and activity logs has been a valuable asset as we strive to answer this question.

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