Empirical analysis and evaluation of a metadata scheme for representing pedagogical resources in a digital library for educators

Abstract: This paper introduces the Just-in-Time Teaching (JiTT) digital library and describes the pedagogical nature of the resources that make up this library for educators. Because resources in this library are stored in the form of metadata records, the utility of the metadata scheme, its elements and its relationships is central to the ability of the library to address the pedagogical needs of instructors in the work domain of the classroom. The analytic framework provided by cognitive work analysis (CWA) is proposed as an innovative approach for evaluating the effectiveness of the JiTT metadata scheme. CWA is also discussed as an approach to assessing the ability of this extensive networked library to create a common digital environment that fosters cooperation and collaboration among instructors.

1. The Just-in-Time Teaching Digital Library

In 2000, the National Science Foundation [NSF] initiated the National Science Digital Library Program [NSDL] in an effort to promote the development of innovative educational resources and to pioneer original methods for delivery of instruction in science, technology, engineering and mathematics [STEM]. Digital libraries currently funded by the NSDL Program are intended to offer "organized access to collections and services from resource contributors that represent the best of public and private institutions including universities, museums, commercial publishers, governmental agencies, and professional societies" (NSDL 2004, p. 1). While many of the NSDL libraries are focused on the development of digital collections addressing specific areas of instruction (e.g., geoscience, animal behavior, health sciences and microeconomics), there are several libraries whose mandate is to provide instructional support for STEM teachers.

One such library whose primary motivation is to provide support for the classroom activities of STEM instructors is the Just-in-Time Teaching Digital Library (JiTDDL). JiTDDL is a web-based collection of pedagogical resources that have been developed to support the instructional methodology known as Just-in-Time Teaching, or JiTT (Novak et al., 1999). Instructors who have adopted the JiTT approach rely on pre-class "WarmUp" questions to enhance student-teacher interaction in the classroom: prior to class, students are given a carefully constructed web-based (digital) assignment and must submit their responses electronically to the instructor before the start of class. The instructor then reviews the responses from her students “just-in-time” to tailor her in-class instruction to respond to the level(s) of understanding (or misunderstanding) indicated by student responses.

JiTTL methods have been adopted in a number of high school and college classrooms throughout the United States: currently, there are approximately 400 instructors in 25
different disciplines at more than 100 different institutions who have implemented this pedagogical method. JiTT instructors represent a wide range of disciplines from the humanities (history and journalism), the social sciences (accounting, finance, economics and psychology), the hard sciences (astronomy, biology, chemistry, geology and physics), the applied sciences (nursing and engineering), and mathematics. Collectively, these instructors have amased an impressive storehouse of several thousand JiTT-based resources, including digital simulations, follow-up classroom activities, assessment tools and instructional support materials as well as pre-class warmup questions. In addition to these instructional materials, many JiTT instructors have also accumulated a wealth of examples of student responses to specific JiTT assignments; and these collections of student responses have frequently been analyzed and annotated by the contributing instructors to illustrate various levels of student understanding. The JiTT Digital Library is intended both to provide a centralized storehouse or archive for storage and exchange of these JiTT resources and to serve as the platform for development of an interactive, online community where instructors can collaborate on the revision, enhancement and extension of existing resources as well as the development of new materials.

In the JiTT digital library, each resource exists only as a metadata record; that is, a resource is stored in a relational database as a set of element-value pairs, or statements. This mode of representation was chosen, in part, because it allows the individual instructor to tailor online presentation of retrieved resources by selecting only those elements of the metadata record that are relevant to her immediate need. For example, one instructor, having retrieved a set of resources dealing with a particular topic, might want to display nothing more than the description, audience level and required student reading(s) for each resource; another instructor, having already selected a particular warmup question or in-class activity, might want to view previous student responses and comments from other JiTT instructors as to how student responses to this question were used to structure in-class presentation of the instructional content. Storing each resource in the form of a metadata record provides the flexibility of presentation necessary to meet the very different needs of JiTTDL users.

Another important consideration that influenced the selection of metadata records as the format for storing JiTT resources was the need to support the potentially dynamic nature of resources in the JiTT library. One of the primary objectives of JiTTDL is support for collaboration in the development and evolution of resources and for the exchange of in-class experiences among JiTT instructors. By storing a JiTT instructional resource as a metadata record, any registered member of the JiTT online community can comment on the success of certain JiTT materials, report student responses to a particular activity, or share modifications in the application of an existing resource. If resources were stored in the library as either html or pdf documents, for example, the process of updating an existing resource in a timely fashion would be a cumbersome task. In contrast, storing each resource as a metadata record allows for dynamic updating of existing resources as well as the attribution of authorship for new or modified content while simultaneously, maintaining in its original form, the intellectual content and authorship of the original resource.

The metadata scheme used to represent JiTTDL resources was designed to provide basic information about a resource (e.g., author of the resource, discipline, type of activity or assignment, topic, audience level, etc.) and to address a set of questions that might typically be posed by an instructor (e.g., What classroom strategies have been used with this assignment? Are there assignments that lead up to or follow from this activity?). These questions were gathered from novice and expert JiTT implementers during a series of JiTT workshops and were analyzed to identify additional data elements that would be of value to instructors; but the basic element set was developed based on the intuitions of a small group
of researchers, only one of whom was an experienced JiTT instructor. And, while metadata elements were extended and refined during an iterative process of application and revision, the utility and appropriateness of the metadata scheme for the community of JiTT instructors was not evaluated during the process of scheme development.

This paper reports on the use of cognitive work analysis (CWA) as a theoretical framework for evaluation of the JiTT metadata scheme in order to determine how well the scheme supports the instructional needs of JiTT instructors both in the work domain of the classroom and in the collaborative environment provided by the digital library.

2. Cognitive Work Analysis

Cognitive work analysis (Rasmussen, Pejtersen & Schmidt, 1990; Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999; Sanderson, 2003) provides a theoretical and methodological framework for a work-centered approach to the design of large-scale information systems and the empirical investigation of how information technology changes human conditions of work. Because the CWA framework originated in the cross-disciplinary and problem-oriented international research environment of Risoe National Laboratory, Denmark, it has drawn on a diversity of theoretical backgrounds ranging from general systems theory to cognitive psychology and the sociology of work (see Rasmussen, Pejtersen and Goodstein, 1994; Albrechtsen et al., 2001; Sanderson, 2004; Hollnagel and Woods, 2005). In addition, field studies and field experiments addressing users’ work activities with information technology in a variety of work domains have contributed to the development of CWA as a generic approach to the analysis of work environments and the evaluation of complex information systems.

While CWA does not prescribe particular theoretical perspectives for the researcher, it does offer an integrative approach to analysis of work domains and the evaluation of complex information systems. The first key feature in the development of this approach was the taxonomy of work described by Rasmussen (Rasmussen, Pejtersen & Schmidt, 1990). Based on empirical findings from field studies and field experiments, the taxonomy of work represents the various aspects of work domains, work tasks and users. To include the perspective of human-computer interaction, the original taxonomy was extended by Rasmussen’s skills-rules-knowledge taxonomy (Rasmussen, 1983), thereby developing a broader framework for systems analysis and design. Taken together, the taxonomy of work and the taxonomy of human-computer interaction constitute the conceptual framework of cognitive systems engineering (CSE), which comprises the analytical framework of CWA (Rasmussen, Pejtersen & Goodstein, 1994).

A major challenge in the development of CWA has been coupling the understanding of information systems as sociotechnical systems (which focuses on the collective features of domains and systems) with an emphasis on the cognitive aspects of information system use (which focuses on individual users’ preferences, knowledge and strategies). Continuing development of the framework has addressed the collective aspects of information system use, for example, through empirical analysis of collaborative information searching (Fidel et al., 2004) and collaborative knowledge organization (Albrechtsen, 2003; Albrechtsen et al., 2004). The research described here represents a new application of CWA as a framework for evaluating the utility of a metadata scheme within a specific work domain. More importantly, this innovative application of CWA involves the analysis and evaluation of knowledge sharing in large-scale information systems such as the JiTT digital library with the ultimate goal of developing a framework for describing explicit as well as implicit knowledge architectures in complex digital collaborative environments – knowledge
architectures that can guide the design of work-based and user-centered knowledge organization schemes.

3. The Means-Ends Abstraction Hierarchy
   The core of CWA is the means-ends model which is used to analyze the stable properties of a work domain and thus functions as the glue joining analysis and evaluation of the work domain. The means-ends model addresses the overall territory of work in terms of domain structures and user work strategies on the one hand and user resources, backgrounds and preferences on the other.

   The means-ends model described by Rasmussen (1986) was originally introduced as a paradigm for representing engineering control systems such as those used in power plants. Since its introduction, the means-ends model has been the object of much discussion and ongoing development by the CSE research community concerned with human-machine systems design (e.g., Lind, 1999). Use of the means-ends model has recently been extended beyond CSE and has been applied to research on the design and evaluation of information systems serving a broad range of application domains. Adaptations of the means-ends model in various domains have been discussed in Vicente (1999), in Rasmussen, Pejtersen and Goodstein (1994), and in Rasmussen, Pejtersen and Schmidt (1990). Specific applications have ranged from patient care in hospitals and case handling in public institutions to knowledge exploration and organization in digital libraries and web-based collaboratories (Pejtersen & Albrechtsen, 2002; Albrechtsen et al., 2004).

<table>
<thead>
<tr>
<th>MEANS-ENDS RELATIONS</th>
<th>PROPERTIES REPRESENTED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals and Constraints</td>
<td>Properties necessary and sufficient to establish relations between the performance of the system and the reasons for its design (i.e., the purposes and constraints of its coupling to the environment).</td>
</tr>
<tr>
<td></td>
<td>Categories in terms referring to properties of the environment.</td>
</tr>
<tr>
<td>Priority Measures</td>
<td>Properties necessary and sufficient to establish priorities according to the intention behind design and operation: topology of flow and accumulation of mass, energy, information, people, monetary value.</td>
</tr>
<tr>
<td></td>
<td>Categories in abstract terms referring neither to system nor environment.</td>
</tr>
<tr>
<td>General Functions</td>
<td>Properties necessary and sufficient to identify the &quot;functions&quot; that are to be coordinated irrespective of underlying physical processes.</td>
</tr>
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<td></td>
<td>Categories in terms of recurrent, familiar input-output relationships.</td>
</tr>
<tr>
<td>Processes and Activities</td>
<td>Properties necessary and sufficient for control of physical work activities and use of equipment: to adjust operation to match specifications or limits; to predict response to control actions; to maintain and repair equipment.</td>
</tr>
<tr>
<td></td>
<td>Categories in terms of underlying physical processes and equipment.</td>
</tr>
<tr>
<td>Physical Resources</td>
<td>Properties necessary and sufficient for classification, identification and recognition of particular material objects and their configuration and for navigation within the system.</td>
</tr>
<tr>
<td></td>
<td>Categories in terms of objects, their appearance and location.</td>
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Figure 1: The means-ends abstraction hierarchy. (Reprinted from Rasmussen, Pejtersen & Goodstein (1994) with permission of the authors.)
Means-ends analysis is based on two fundamental strategies: (a) empirical analysis of work domains and (b) mapping of identified domain features in a means-ends abstraction hierarchy (Rasmussen, 1986; Rasmussen, Pejtersen & Goodstein, 1994). This abstraction hierarchy is designed to capture all relevant features of the work domain, from high-level, abstract attributes such as goals and constraints to very concrete elements in the form of material resources. As represented in Figure 1, the means-ends abstraction hierarchy consists of five levels:

- **Goals and Constraints**: The highest level of abstraction in the means-ends hierarchy addresses the purpose of the work domain in relation to its functions in the environment and captures the work domain’s anchoring in cultural, political and economical systems. Examples of goals are found in statements of policy formulated for the work domain, while examples of constraints are to be found in the outside regulations imposed either by legislation or by codes of practice.

- **Priority Measures**: The second level of abstraction addresses the organizational structure of the work domain and the division of labor and distribution of resources within the domain – how resources like staff, material and finances are allocated and managed within the domain.

- **General Functions**: The third level of abstraction addresses the recurrent tasks carried out in a work domain, irrespective of those physical resources, such as staff or tools, which may be involved in carrying out such tasks.

- **Physical Processes and Activities**: The fourth level of abstraction addresses the actual activities involved in carrying out workplace tasks – the processes necessary to establish and maintain the general functions of the work domain.

- **Physical Resources**: The fifth and most concrete level of abstraction consists of an inventory of the material resources that are created, used and maintained within the work domain. As discussed by Rasmussen, Pejtersen and Goodstein (1994, pp. 35-55), the category of physical resources includes the actors who participate in the work domain – the staff and users who take part in the activities of the work domain.

Within the theoretic framework of the original means-ends model, the relationships between the five levels of abstraction were understood to be governed by laws of nature, by the structure of the control system, and by the human operator’s interpretive and decision-making activities within the limits set by the environmental constraints of the work domain. Current theory informing means-ends analysis views these environmental constraints as sources of regularity that inform the actors’ decisions and freedom of choices rather than as conditions that causally determine the actors’ activities and understandings, as is the case with work systems such as those associated with power plants. Recent adaptations of means-ends analysis emphasize work systems as territories where the user navigates more or less freely. The conditions for user decision-making are not determined by natural forces, nor are they prescribed by the information system itself; rather, they develop dynamically through the interdependencies and relationships established between users. When applied in user-centered work domains, means-ends analysis addresses the ongoing construction of the territory of work within which users will navigate. Accordingly, recent applications of the means-ends model, ranging from concurrent engineering (Pejtersen et al., 1997) to collaborative knowledge organization in film research (Albrechtsen, 2003), have focused on mapping the work domain in terms of common or shared workspaces within which collaborating users navigate.
4. Application of CWA to Analysis of the JiTT Digital Library

CWA integrates traditional areas of investigation through analysis of the relevant knowledge domain(s); analysis of the organizational domain, including how work is divided, delegated, managed and financed; analysis of the work domain, including specific tasks, decision-making strategies and heuristics, and domain vocabulary; and analysis of user skills, performance criteria, preferences and expectations. The objective of CWA is to analyze these various elements of the work domain to develop an understanding of the structural, social and individual components that constitute a "system of work". While the various areas of investigation are treated as analytically distinct, the overall emphasis of CWA is on developing a comprehensive understanding of the relationships that exist among the structural, social and individual components of the work domain and how these relationships interact to produce a "system of work" that is greater than the sum of its parts.

CWA offers a theoretical framework and a set of heuristic models that are being applied both in analysis of the classroom as work domain and in evaluation of the JiTT digital library as a large-scale networked information system. The means-ends abstraction hierarchy and the task situation model are two key features of the CWA framework that are being used in the empirical analysis of the JiTT metadata scheme and its role in supporting the functional components of the JiTT digital library. The means-ends hierarchy is being used to map the work domain of the classroom from goals and priorities to functions, processes and physical properties. As such, it is providing a multi-faceted representation of the territory in which JiTT resources are being applied by instructors. The task situation model complements the means-ends hierarchy by providing guidelines for empirical analysis of the prototypical activities in which JiTT instructors are involved – task situations such as construction of assignments, evaluation of student responses, classroom instruction and interaction with students.

Initial data collection is relying on artifact-based interviews with JiTT instructors. Because the goal of this research is to evaluate the metadata scheme and the contribution of JiTTDL as a collaborative workspace, these open-ended interviews have attempted to elicit information regarding the process of selecting, adapting and implementing a JiTT activity, the analysis of student responses to warmup questions, and the contribution of this analysis to in-class instruction. Preliminary analysis of the means-ends hierarchy developed from these interviews appears to indicate a high degree of diversity in the expertise instructor's bring to application of the JiTT methodology as well as in the knowledge content of resources used by individual JiTT instructors. At the same time, the work domain supported by JiTTDL is characterized by common work functions such as development of lesson plans, classroom instruction and student tutoring. This juxtaposition of diversities and commonalities among JiTT instructors raises interesting questions regarding instructor comfort with the JiTT pedagogy and the relationship of evolving comfort levels to the adoption, adaptation and modification of JiTT activities in the classroom.

The JiTT digital library is intended to provide instructors with the resources and functionalities that will create a dynamic environment in support of the work domain of education and to construct a shared virtual workspace where instructors can collaborate on the design of innovative instructional resources and techniques. Preliminary findings of this analysis indicate that, while the common workspace offered by the JiTT digital library has encouraged changes in the activities and processes used by instructors to carry out the general functions characteristic of classroom instruction, these activities remain closely tied to the goals established by the policy pronouncements of individual educational systems and, in some cases, by the constraints imposed by state legislation. Initial findings also indicate that the JiTT digital library supports mutual learning and innovation through the
sharing of expert knowledge across instructors, that it promotes awareness of the wide range of interactive resources available to instructors and that it encourages coordination of work among instructors.

More importantly, however, these preliminary findings suggest that ongoing alterations in the common work space – alterations following from the instructors' evolving understanding and articulation of the content of educational work – will require modifications in the scope of the current JiTT metadata scheme. However, it is becoming increasingly clear that, in order to explore how modifications in the representation of these resources will accommodate instructors' use of JiTT resources and encourage an evolving semantics within the common work space, it will be necessary to evaluate the efficacy, efficiency and utility of the metadata scheme through empirical field experiments that involve both instructors and students in interactive task scenarios designed to explore a pre-defined set of pedagogical techniques and resources.

5. Conclusion

This paper has presented the theoretical foundation for an innovative approach to the evaluation of both a domain-specific metadata and a specialized digital library. Prior to the current effort, CWA had been applied in the evaluation of information retrieval systems and relatively small and cohesive digital libraries and collaboratories such as Collate (Albrechtsen et al., 2004). The information environments in which CWA has been applied have not been part of a larger digital library context, as is the case with JiTTDL. Although the collection of empirical data is still in process, the use of CWA as a tool for evaluating the utility of metadata schemes appears promising. CWA provides a comprehensive approach to understanding the scope and complexity of a system of work by integrating the analysis of the human component in the work environment (including, for example, decision-making strategies and heuristics, domain vocabulary and user preferences and expectations) with the more traditional analysis of knowledge domains and organizational structures. It is precisely this comprehensive approach to analysis of the work domain that makes CWA an attractive framework for the evaluation of a work-specific metadata scheme as well as for assessment of the effectiveness of the shared and networked environment provided by the JiTT digital library.

References


