WORK ACTION ANALYSIS TO STRUCTURE PLANNING AND FORMATIVE EVALUATION OF AN ENGINEERING COURSE USING A COURSE MANAGEMENT SYSTEM

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Work Action Analysis to Structure Planning and Formative Evaluation of an Engineering Course Using a Course Management System

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Soli Deo Gloria

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SUMMARY

Cognitive engineering, by identifying behavior-shaping constraints, provides methods for design and evaluation of complex socio-technical systems. However, traditional methods examine only one type of constraint, either cognitive or environmental. In learning service systems such as education, both cognitive and environmental constraints must be examined together. Improved methods of planning and formative evaluation are needed for engineering education and other learning service systems. Therefore, this dissertation develops a new cognitive engineering method, Work Action Analysis (WAA), that is able to capture cognitive and environmental constraints in a single model. The WAA model represents a learning service system on three dimensions: means-end decomposition, parts-whole decomposition, and roles of cognitive agents. WAA also provides methods for developing and using this model in planning and formative evaluation. The WAA method for planning evaluation explicitly represents the evaluator's mental model of a learning service system and examines its alignment to guide its design. The WAA method for formative evaluation then takes the WAA model and interprets evaluation measures in the context of the model. As a demonstration, the methods for planning and formative evaluation are applied to a portion of an undergraduate engineering course. To provide measures for formative evaluation of a course, a centralized evaluation component that collects performance, perception, and process measures was added to an Internet-based course management system. The WAA methods provide insights to the design and operation of this learning service system, including recommendations that could be implemented during instruction. The theoretical implications of the WAA model of learning service systems,

and further extensions of WAA, are also discussed.

CHAPTER 1

INTRODUCTION

Evaluation is necessary for any system to ensure it is meeting or has met its stated goals. Evaluation must take place throughout the life cycle of a system, i.e., during design, operation, and end-of-life analysis. During design, evaluation assesses the ability of the system to meet its specified needs (Dieter, 1983). During operation, evaluation is needed to assess if the system is meeting the specified goals. The need for evaluation has led to the development of many methods such as process control, quality control and quality engineering in the manufacturing domain. Finally, at the end of an operational cycle, the system should be evaluated to determine whether the system was effective and should be implemented again. As seen in various methods for design (Dieter, 1983; Pugh, 1991; Ulrich & Eppinger, 1995), a traditional primary focus in engineering is on technological systems. However, engineering design methods could also be applied to learning service systems, which are systems where the service of teaching knowledge or cognitive skills is provided by at least one agent to at least one other agent desirous of learning them.

This dissertation examines evaluation in the learning service system of undergraduate engineering courses. "Evaluation in the context of educational systems is defined briefly as examining the effectiveness of an educational system (or component of that system) in meeting learning and teaching goals" (Nickles, Pritchett, & Trotti, 2001). In education, the forms of evaluation are categorized by when they take place in the life cycle of the system. A *planning evaluation* (Stevens, Lawrenz, & Sharp, 1993) is performed on a course as it is being designed. In this evaluation, the evaluator specifies expectations for the course in terms of the objectives, activities he or she expects students to perform, and the content. The evaluator can then examine these expectations to determine the appropriateness of the educational methods and materials relative to the objectives. While the course is in progress, a *formative evaluation* is conducted to measure how well the teaching and learning goals are being met (Stevens et al., 1993) and if the course is operating as expected. A *summative evaluation* is conducted once the course is completed and examines the success of the system overall in meeting the specified objectives and expectations for operation (Stevens et al., 1993).

The pursuit of more and better evaluation of engineering education is being driven by pressure from various sources including accreditation boards, e.g., the Accreditation Board for Engineering and Technology (ABET), and those calling for more efficient and effective engineering education (CASEE, 2004; NRC, 1995). The Center for the Advancement of Scholarship on Engineering Education (part of the National Academy of Engineering) emphasizes the need for research in effective evaluation methods in engineering education. They specifically call for more research on strategies and technologies that enhance the effectiveness of faculty instruction (CASEE, 2004), which requires faculty to evaluate their own methods to identify where improvement is needed.

Also, though some amount of summative evaluation is a relatively common practice, evaluation activities are not needed just at the end of the life cycle of an educational system. For example, while most ABET accreditation criteria refer to aspects of the system that should be examined in a summative evaluation, criterion 2(d) calls for "a system of ongoing evaluation that demonstrates achievement of these objectives and uses the results to improve the effectiveness of the program" (ABET, 2002-2003) (p. 1).

Students in the current life cycle of the system will be affected by any deficiencies; thus these deficiencies should be discovered and removed, if possible, during the course or even before students take the course. Therefore, this dissertation focuses on planning and formative evaluation in undergraduate engineering courses.

Planning and formative evaluations need to be performed using rigorous, structured methods, similar to the many engineering design methods available for technology design (e.g., Dieter, 1983; Pugh, 1991; Ulrich & Eppinger, 1995). A major benefit of an engineering design process is that its structure leads to completeness, i.e., it considers all the relevant aspects of the design and its operational environment. Another benefit of engineering design is the use of models to examine and describe the design at an appropriate level of detail before the actual system is implemented.

It is not known exactly how frequently or with what level of rigor engineering instructors perform planning and formative evaluations in their courses. In practice, instructors may informally perform planning evaluation as they design their courses. When the course has started, instructors may regularly and spontaneously evaluate using readily available data, including grades on assignments and tests, perceived student engagement in class, and the nature of student questions. In a survey conducted by Nickles, Pritchett, and Trotti (Nickles et al., 2001), engineering instructors across the United States reported performing 1.77 evaluations on average during each course. Even if this value only indicates the number of formal, purposefully implemented formative evaluations, they are still infrequent. Likewise, the survey did not require respondents to differentiate between planning, formative, and summative evaluations. For example, 89% of instructors surveyed reported using surveys provided by their institution, which includes institute-wide end-of-course surveys. These surveys can be seen as either formative to the development of a course across semesters or summative to the course taught in a single semester. If the focus is on summative evaluation of individual courses, the frequency of planning and formative evaluation may be lower than 1.77. The survey responses also did not describe the level of rigor of the evaluation methods used.

To support formative evaluation, educational measures must be collected in an efficient and timely way and presented to the evaluator in a manner consonant with evaluation methods. One potential source of data is an Internet-based course management system (CMS). A CMS (or course management tool) has been defined as "a tool specifically designed for the management and delivery of educational content via the Internet" (St. Clair & Baker, 2003). Among the functions CMS software typically provide are distributing information to the class, allowing students to submit work and receive grades, and providing communication tools between instructors and students. When a CMS is an integral part of a course, it can also be used in several ways to collect evaluation data. As they use the CMS, students can be presented with anonymous surveys to collect their perceptions of the course or assessments to measure their performance. If students' grades on assignments are stored in the CMS, they provide measures of performance. In addition, students' interactions with the CMS can be logged and examined for patterns. Since this data is electronically stored, much of it could be automatically analyzed and presented to the evaluator. However, while individual instantiations of these measures have been implemented through the Internet, they have not yet been integrated together for comprehensive formative evaluation.

1.1 Applying Cognitive Engineering to Evaluation of Learning Service Systems

Cognitive engineering has been defined as "the multidisciplinary area of research that is concerned with the analysis, design, and evaluation of Complex, Sociotechnical Systems " (Vicente, 1999, p. 5, capitalization his), where a sociotechnical system has technical, psychological, and social elements (Vicente, 1999, p. 9). Dainoff et al. assert that education qualifies as a sociotechnical system and can be examined by the methods of cognitive engineering (Dainoff, Mark, Hall, & Richardson, 2002). This dissertation specifically asserts that cognitive engineering methods can aid the planning and formative evaluation of learning service systems such as engineering education. In support of this assertion, others have observed that education can be viewed as a system and evaluated as such (Brown, 1992; Biggs, 1993; CASEE, 2004). In fact, one of the earliest calls for a discipline of cognitive engineering grew out of observations on how it could be applied to education, though it has not been thusly applied (Norman, 1980). For guidance on how to apply cognitive engineering to support educational evaluation, it is important to examine how cognitive engineering has been applied to similar systems.

1.1.1 Analogy of Educational Evaluation to Process Control

Planning and formative evaluation of education are similar in many ways to the design and operation of a process control task. Process control is a fundamental part of domains such as manufacturing and power generation. In process control, the human operator seeks to maintain the system's operational processes so that it continues to produce the desired output. Process control can be viewed as a control feedback loop, where the operator examines measures taken of the system, considers them in light of the operator's expectations for system behavior, and then manipulates the system to conform to the desired behavior.

Without measures, the process controller cannot know the current state of the system. However, measures will have various levels of validity and reliability in how well they are able to indicate any particular state of the system without unambiguous interpretations. Rather, the operator must judge whether or not they expected a measures' value and act upon their interpretation of it.

To interpret the meaning of a set of measures and to identify and trace its underlying causes, the operator must rely on a model of the system: "…it is well known in linear systems theory that, implicitly or explicitly, every good controller must be, or possess, a model of the system it is controlling" (Vicente & Rasmussen, 1992, p. 590). In many cases of process control, the operator is provided with an explicit model by the designer in the form of documentation or a control interface. In addition, the operator has a mental model of the system that is also used to guide behavior and which may be informed by the explicit model. Johnson-Laird observes that "human beings understand the world by constructing working models of it in their minds" (1983, p. 10). Cognitive engineering also recognizes that the operator has an internal *mental model* of expected system behavior. Norman speaks of these models as "the models people have of themselves, others, the environment, and the things with which they interact" (Norman, 1988, p. 17). Vicente defines mental models as "an internal symbolic representation of the relational structures in the environment" (1999, p. 282).

While a mental model may or may not accurately reflect the actual system or be comprehensive, it shapes the operator's behavior in significant ways (Norman, 1986). An operator's mental model is important to consider during design since, if the mental model is not comprehensive or accurate, the operator may have wrong expectations of the system. Cognitive engineering provides methods to make a mental model explicit to improve its consistency and comprehensiveness with respect to the true system. Through a systematic process of making a mental model explicit, the operator must confront the gaps and inconsistencies in that model and resolve them as part of the design process.

Cognitive engineering has studied the domain of process control for over two decades (e.g., Rasmussen, 1983; Rasmussen & Goodstein, 1987; Bisantz & Vicente, 1994; Burns, 2000). This research has brought insights to many aspects of process control, including operators' mental models of the system including several different levels of abstraction (Rasmussen, 1985). The system model at each level of abstraction represents one aspect of the complete system. These levels of abstraction are related as a means-end hierarchy: system elements at one level of abstraction are the means for accomplishing the related elements of higher levels of abstraction. The relationship also holds in the opposite direction: elements at one level of abstraction are the ends or purpose for accomplishing the related elements of lower levels of abstraction. The levels of abstraction commonly used in explicitly modeling process control include the physical objects of a system, the physical actions that can be taken, the general functions the system performs, the general flows of mass, energy, and/or information as immediate goals of the system, and the overall goals of the system (Rasmussen, 1985; Bisantz & Vicente, 1994).

Cognitive engineering provides several methods for modeling a system, including hierarchical task analysis, work domain analysis, and control task analysis (Rasmussen, Pejtersen, & Goodstein, 1994). Making the operator's mental model explicit is one major benefit to this work, as it can lead the operator to contemplate and modify the model in order to capture the system more accurately. Such models developed in cognitive engineering have been used to design interfaces that support the control task of the operator at several levels of abstraction (Vicente, 2002; Vicente, Christoffersen, & Pereklita, 1995; Vicente & Rasmussen, 1992). In addition, cognitive engineering methods can be used in the design of a system before it has been built to ensure the task environment matches the operator's capabilities (Rasmussen et al., 1994).

The same general characteristics of the method used to design a process control system can be applied to the design and planning evaluation of learning service systems such as educational courses. Designing an industrial process requires a rigorous, structured engineering design method, which includes modeling the relevant aspects of the system that are explicit and implicit in its operation such as physical objects and system goals. Similar representations would support evaluation of a learning service system during design. The instructor would represent his or her expectations for the system in a comprehensive framework, making changes to the design and his or her expectations as the representation is made explicit.

In addition to examining the design of the learning service system beforehand, formative evaluation can be performed as it is in progress to determine what improvements can be made. Continuous improvement in engineering education courses, for example, requires instructors to adapt their instruction through several mechanisms, such as changes in presentation of material, changes in instructional methods and pedagogy, changes in course administration, and changes in their methods of grading student assignments.

Formative evaluation of education is similar conceptually to the task of process control in several ways. Formative evaluation can be seen as a control feedback loop where the evaluator, like the process controller, must rely on human judgment to perform an evaluation, using the mental model and imperfect measures to assess the current state of the system. Just as in process control, a measure can give an indication of a system variable, but it can not directly indicate the underlying causes. This dissertation asserts that learning service systems would greatly benefit from this rigorous, model-based pattern as it would establish more formal planning evaluation. As in process control, the model used in formative evaluation must be comprehensive so that all relevant aspects of the system can be considered in the evaluation process but must also provide sufficient detail to pinpoint effective interventions. The instructor can modify many aspects of the system to meet expectations as well as adjust expectations when necessary.

While there are many similarities between process control and educational evaluation, there are also several differences which are summarized in Table 1. Two major differences relate to the constraints that are imposed on the operator and evaluator. In process control, the operator's behavior is viewed as an adaptation to the constraints imposed by the physical environment. In most cases, the operator cannot make significant changes to the physical equipment or to the sequence of operations performed. Thus, these external, physical constraints are relatively static. In contrast, an instructor can create new material and learning activities for students at any time and can give students the ability to create their own learning activities. In addition, the designer must recognize how student and instructor behavior is also constrained by their cognitive capabilities. For example, meeting specific learning goals may require a combination of cognitive activities and physical actions, using a variety of artifacts and information sources, by both the instructor and students.

Table 1: Process Control vs. Formative Evaluation of Education

	Process Control	Formative Evaluation of Education
Primary Source of Constraints	External, physical environment	Internal, cognitive activities
Evaluator's Ability to Change Constraints	Physical constraints are fixed, static	Physical constraints are flexible, changeable
Sequence of System Operations	Typically defined and distributed to controllers, sometimes strictly sequential	Some are defined by the instructor, students have freedom to select sequence of actions
Designer and Evaluator Roles	Separate designer and operator roles	Instructor may take both roles; possible to have different people for roles of designer, instructor, and evaluator
Evaluator's Expertise	Well trained, skillful operators	Varied training and experience, some training undertaken voluntarily, practice is often on the job
Visible System Design Model	Visible model often explicitly provided to the operator	Visible model not necessarily provided, except in a very general sense

In process control, well-defined procedures for operating the system are typically distributed to the operators. These procedures tend to be very sequential and exactly specify which actions need to take place at what time to keep the system within the bounds of stable operation. One consequence of this is that operators have comparatively consistent training and methods of operation. Another consequence is that operators are typically given a representation of the system, both in terms of the procedures themselves as well as interfaces that support procedure following. In many cases, many different, explicit representations of the system are available, for example in the form of blueprints or chemical flow diagrams, that are complete and comprehensive relative to their purpose and scope.

In contrast to process control, education has less emphasis on fixed physical elements and on a stable operation state. Thus, it is difficult to design procedures that apply to every situation in education. Also, formal training on planning and formative evaluation is not typically given to all instructors, though it may be available. Even when instructors do receive training, the opportunity to practice what they learn is typically done on the job. Finally, a representation of the course may not be provided to the instructor, and, if a representation is provided, it may not accurately reflect that instructor's mental model. Instructors often create some explicit representations of some aspects of their mental model. For example, course administrative material such as a syllabus can serve to identify course goals, general topics covered in the course, and a schedule of assignments. However, these are not comprehensive course models that identify every item of content and activity used for learning. Also, administrative materials typically do not describe a course at a level of detail needed for systematic, thorough planning and formative evaluation.

The many conceptual similarities between process control and formative evaluation suggest that the cognitive engineering techniques used to study the former can be applied to bring insight to the latter. However, the differences show that traditional methods used in process control cannot be immediately and directly applied to evaluation of learning service systems. With respect to this, Pejtersen and Rasmussen (1997) suggested that there is currently no single modeling framework in cognitive engineering that is adequate to model a learning situation for evaluation.

1.2 Objectives

The objectives of this dissertation are:

1. Develop a work action analysis model that can be applied to represent learning service systems, such as education;
2. Develop a method for planning evaluation where a representation of the system is created using work action analysis and is used to evaluate the system design;
3. Develop a set of measures for formative evaluation that can be administered through a CMS with built-in data collection and analysis capabilities;
4. Develop a method for formative evaluation using the model and measures; and
5. Demonstrate the use of work action analysis by performing planning and formative evaluations on an undergraduate course using measures collected from the CMS.

1.3 Overview of Dissertation

This dissertation describes a new cognitive engineering method called work action analysis. This method and its associated model combines strengths from work domain analysis and cognitive task analysis to model learning service systems, such as education, where both cognitive and environmental constraints need to be captured and key system elements include human actions in addition to physical elements and system goals.

This dissertation will then specifically focus on the development of a model and methods that are suitable for planning and formative evaluation of undergraduate engineering courses. This dissertation will also examine ways to collect measures of education through a CMS and to use these measures together with a representation of the course for formative evaluation.

As a demonstration, work action analysis has been used to perform a planning evaluation of a portion of an undergraduate engineering course that heavily relies on a CMS, ISyE 4009, the senior level “Introduction to Human Integrated Systems” course, at Georgia Tech from the spring, 2003 semester. The work action analysis model resulting from the planning evaluation was used in conjunction with the measures collected through the CMS for formative evaluation of the course.

The dissertation ends with a broader discussion. The contribution of this work to the field of cognitive engineering is examined, including the theoretical implications of models examining both cognitive and environmental constraints. Benefits and limitations of applying WAA to evaluating learning service systems are discussed. Finally, future directions for research are noted.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Cognitive Engineering

2.1.1 Definition

Cognitive engineering has been defined in a variety of ways. Woods and Roth define it as “an applied cognitive science that draws on the knowledge and techniques of cognitive psychology and related disciplines to provide the foundation for principle-driven design of person-machine systems” (Woods & Roth, 1988, p. 415). Vicente has defined it as “the multidisciplinary area of research that is concerned with the analysis, design, and evaluation of Complex, Sociotechnical Systems” (Vicente, 1999, p. 5, capitalization his). These definitions of cognitive engineering share the theme of designing and evaluating complex systems where humans and technology interact.

This work uses Vicente's definition of complex sociotechnical systems to identify the systems to which cognitive engineering can be applied (Vicente, 1999, p. 9). Vicente’s definition points out that the focus in cognitive engineering is on complex, sociotechnical systems, where humans and technology interact to achieve goals. Also, cognitive engineering considers the whole system, including interactions between elements, rather than attempting to isolate elements and study them individually. Vicente lists eleven characteristics of complexity in systems: large problem spaces, social, heterogeneous perspectives, distributed, dynamic, hazardous, coupling, automation, uncertainty, mediated interaction, and disturbances. He notes that a system can be considered complex if it qualitatively "rate[s] highly on at least some of these dimensions, and will also usually exhibit several other dimensions of complexity albeit to a lesser extent" (Vicente, 1999, p. 17).

These definitions also note why cognitive engineering is applied to systems: for design and evaluation. In cognitive engineering, the evaluation of a system or proposed system is often used in designing the system or interfaces for humans to control the system, for creating and testing operating procedures, for establishing training requirements for personnel, and for monitoring performance during operations.

2.1.1.1 Focus on Constraints in Cognitive Engineering

Much of cognitive engineering is based on the view that workers performing a task operate within constraints, or boundaries, that shape their behavior. “The basic idea is that the behavior exhibited by workers over time is generated by, or emerges from, a confluence of behavior-shaping constraints that specify the dimensions that must be incorporated into a framework for work analysis” (Vicente, 1999, p.34). A work task can be modeled by identifying constraints on behavior, which will specify the space in which workers can operate. This modeling method can be used for design of new systems or in the re-design or evaluation of existing systems to identify how to constrain behavior for safety, efficiency, or other factors.

The two categories of constraints that are typically considered in cognitive engineering are cognitive constraints and environmental constraints; these constraints are considered with respect to a single worker (Vicente, 1999). Cognitive constraints originate internally due to human cognition (Vicente, 1999). Environmental constraints arise from factors that are external to the worker. “For example, the physical and social reality that serve [sic] as the context for workers’ behaviors are environmental constraints because they exist independently of what any one worker might think” (Vicente, 1999, p.

47). Typically, cognitive engineering analysis methods focus on identifying either cognitive or environmental constraints, but not both. Thus, more than one method has traditionally been used when both types of constraints must be considered in design or evaluation.

2.1.1.2 The Ecological Approach of Cognitive Engineering

Given its recognition of environmental constraints, many methods in cognitive engineering take an ecological approach to examining systems (Woods & Roth, 1988). This approach is based on work in ecological psychology (e.g., Gibson, 1979), which focuses on studying real world situations in their naturalistic environment rather than those created in a laboratory. Also, as opposed to the approach of most of cognitive and experimental psychology which isolate inherent cognitive abilities and limitations of humans, the ecological approach "puts much more emphasis on analyzing the interaction between people and their environment" (Vicente, 1997, p. 3).

In the cognitive engineering community, the environment is seen as a significant determinant of behavior. Simon presented an illustration of an ant moving across a beach to demonstrate the influence of the environment (Simon, 1981). An ant may follow a highly irregular path between two points on a beach which seems to follow no logical pattern. However, if the beach is considered an environment in which the ant acts, the contours and obstacles explain the path that the ant chose based on its abilities. “Viewed as a geometric figure, the ant’s path is irregular, complex, hard to describe. But its complexity is really a complexity in the surface of the beach, not a complexity in the ant” (Simon, 1981, p. 64). Thus, the external environmental constraints must be part of any model of behavior in a given task.

2.1.2 Cognitive Engineering Models

The American Heritage Dictionary (4th Edition) defines the term model as “a schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics” (Pickett, 2000). This definition points out the immediate reason for creating a model: to visualize or describe something. A more specific reason for modeling in cognitive engineering is that it is useful to design or evaluate a system.

Models can be categorized according to their purpose, scope, level of detail, and (for models related to cognition) the determinant of behavior. A model’s purpose identifies how that model will be used. For instance, a model may be predictive and thus have the purpose of predicting the output of the system to given inputs with some level of precision and accuracy. Also, a model may have the purpose of being normative, that is it describes the system, theory, or phenomenon as it should be in the ideal case. Given cognitive engineering’s emphasis on describing naturalistic behavior, many of its models can be descriptive in purpose in that they describe system behavior or many of its phenomena as it actually exists. Likewise, given cognitive engineering’s emphasis on the usefulness of models in design, Vicente describes certain models as formative in purpose, meaning they "focus on identifying requirements - both technological and organizational - that need to be satisfied if a device is going to support work effectively" (Vicente, 1999, p. 110). The word "system" can be substituted for "device" in this quote when using formative models to design systems. It should be noted that a single model and modeling method must be categorized according to how it is used in a particular instance as the same model can be used for different purposes. For example, blueprints for a building are formative while it is being constructed, and are descriptive when it is complete.

The scope of a model identifies the portion of the system that the model intends to capture. A model may attempt to capture all relevant aspects of a system, or only certain portions. There are many ways to distinguish between portions of the system. For example, Rasmussen, Pejtersen, and Schmidt (1990) differentiate between seven major aspects of a work system, including the work domain, typical activities, decision making, information processing strategies, agent roles, management/social organization, and the mental resources, capacity and preferences of the agents. They then identify modeling methods that can be used to capture each of these aspects. Beyer and Holzblatt identify a set of models created during contextual inquiry that also differentiate specific parts of a work system: artifact, cultural, flow, physical, and sequence models (Beyer & Holzblatt, 1998). There are other dimensions along which the scope of a model can be considered, such as time. Systems may have stages of time during which their behavior and operation are distinct from other stages, e.g., startup, operation, changeover, and shutdown. These categorizations are only examples as a model can be devised to cover any or all of a system.

The level of detail of the system that is captured in the model is another dimension of categorization. A model can range in detail from a broad overview of an aspect of the system, giving general concepts, flows, and patterns of behavior, down to specifying each element as precisely as possible. The level of detail may be categorized regardless of the aspect of the system being studied. Physical objects, actions to perform, or goals can be described in very broad or very specific terms. The level of detail must be appropriate to the purpose of the model, so that the greater the detail required for the purpose, the more detail must be included in the model.

Models of cognitive systems can also be categorized according to the aspect of the system seen as driving behavior. As noted previously, the cognitive psychology approach attributes human behavior to internal goals, abilities, and constraints, and cognitivist models focus on these aspects of the system. The ecological approach attributes human behavior primarily to constraints imposed by the environment, and so ecological models focus on these environmental aspects.

Descriptive and formative cognitive engineering models are intended to be useful for explaining human behavior when interacting with a system due to cognitive constraints. The validity of descriptive cognitive engineering models is determined by how much insight they can bring to a system and the behavior of the humans in it. Moray et al succinctly describe this:

> "Another approach to validation is to use the general model to interpret and describe a number of [situations that may occur in the system]. If effective, the model should provide an effective 'language' for describing the operations that are observed under a wide variety of conditions. To the extent that is so, and to the extent that the observed patterns of [human behavior] are consistent with the descriptions provided by the general model, the analysis can be said to be validated" (Moray, Sanderson, & Vicente, 1992, p. 216).

The validity of formative models is similarly determined by the insight they bring to the design process.

2.1.2.1 Discretion of the Modeler

In creating any model, the modeler is responsible for specifying what is to be included in the model and what is excluded. This decision must be made partly based on the general purpose of the model (as defined above) and on the specific use for which it is intended. The characteristics of scope and level of detail must be understood in this context. For example, when modeling a curriculum, an individual course may be considered a single, indivisible element in the system; however, when modeling an individual course, the most elemental level of detail will be much smaller. Also, a curriculum model may include factors such as administrators, industry review boards, and available facilities. When modeling an individual course, the modeler may decide that these factors are not pertinent to the analysis at hand, but may include other factors that are not examined by a curriculum model, such as specific physical actions employed and lists of all hardcopy and electronic instructional materials. All of these factors could be considered when modeling either a curriculum or a course, and the onus is on the modeler to determine what is relevant according to the purpose and specific use of the model.

2.1.3 Modeling Methods in Cognitive Engineering

Cognitive engineering modeling methods have been successful in bringing insight to sociotechnical systems in several domains. Some of the methods used specifically to examine process control are reviewed here, focusing on the characteristics of their associated models.

2.1.3.1 Work Domain Analysis

Work domain analysis captures the structures in the environment where work takes place, and results in a model represented as an 'abstraction hierarchy' (Rasmussen, 1985), also called an 'abstraction decomposition space' (Vicente, 1999). Capturing the structure in which the human works provides insight to the constraints that shape behavior (Simon, 1981). In representing the work domain, an abstraction hierarchy has a scope of the entire system, attempting to capture all relevant aspects of the system. The level of detail required in an abstraction hierarchy is defined by how it will be used, and typically must be sufficient for design and evaluation of the system (e.g., Bisantz, Burns, & Roth, 2002). Work domain analysis follows the ecological approach and so focuses on modeling the physical work domain to reveal the constraints it places on human behavior in the system. Work domain analysis is identified by Vicente as an examination of ecological (or environmental) constraints (Vicente, 1999).

Work domain analysis decomposes a system along two hierarchical dimensions. The parts-whole decomposition divides the system into a hierarchy of progressively smaller sub-systems. This division is broadly applicable and helps manage the complexity of a model of large systems. For example, a manufacturing process can be divided from the overall process into sub-systems, individual machines, sub-assemblies, etc, allowing a designer to consider the parts in relation to the overall system.

The means-end decomposition divides the system into hierarchical levels of abstraction, making a complete representation of the system at each level. For example, in systems governed largely by physical constraints (such as process control), a common form of the abstraction hierarchy includes separate levels for (from lowest level of abstraction to highest) physical form, physical functions, general functions, abstract functions and functional purpose (Rasmussen, 1985; Rasmussen et al., 1994). The specific choice of levels of abstraction depends on the system and the purpose of the model. An example of an abstraction hierarchy for a process control system is shown in Figure 1.

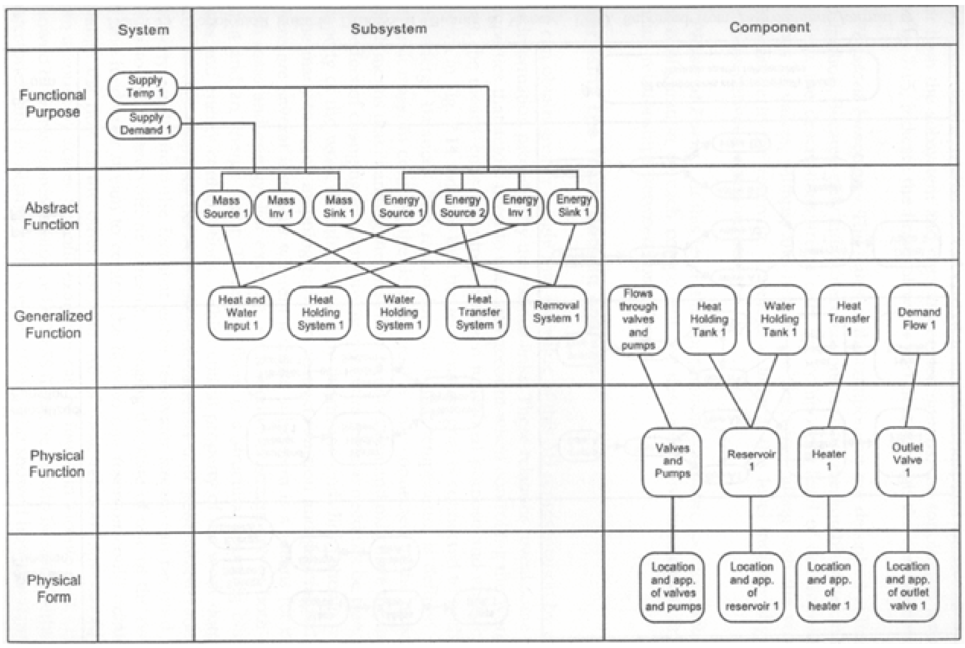

Figure 1: Abstraction hierarchy of the DURESS microworld process simulator, from Bisantz & Vicente, 1994, p. 92[1]

A key part of this model is the hierarchical nature of the levels of abstraction, that is elements at one level are related to elements in different levels through specific types of relationships, indicating their order in the hierarchy. Relations between levels of abstraction in these models are based on *means-end* relations. For any item at one level of abstraction, the related items at the level immediately below (less abstract) should identify the means of accomplishing it, and the related items at the level immediately above (more abstract) should identify the ends for which it is undertaken. For example, with the common levels of abstractions described in the previous paragraph, the individual physical parts that comprise the system determine the physical functions

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[1] Reprinted from the International Journal of Human-Computer Studies, Vol. 40, No. 1, Bisantz, A. and Vicente, K., Making the Abstraction Hierarchy Concrete, Page 92, 1994, with permission from Elsevier

shown above them, from which in turn emerge the general functions, and so on up to the highest abstraction of goals.

Work domain analysis specifically uses *structural* means-end relations between elements of the model. Elements connected by these links describe physical objects or constructs in the environment. "A work domain analysis represents the thing being acted on…work domains are objects of action" (Vicente, 1999, p. 162). In describing the work domain, actions of humans are only implicitly addressed in that these actions are assumed to be responding to and determined by the physical constraints created by the environment. As such, it is not considered appropriate to include actions of humans in this modeling method. "[A] work domain analysis simply cannot be conducted with an action means-ends relation" (Vicente, 1999, p. 162). Thus, work domain analysis' abstraction hierarchy only captures environmental constraints in the work and excludes all cognitive constraints.

Work domain analysis is intended to capture experts' models of work domains (Rasmussen, 1983; Rasmussen, 1985). An expert needs to consider every level of abstraction to control the process, especially during abnormal circumstances and troubleshooting. For example, the expert troubleshooter must recognize the system goals that are not being met, the functions that should be contributing to those goals, and the physical components of the system that are used to accomplish the functions. Thus, the abstraction hierarchy can serve as both a complete representation of levels of abstraction of the system and as a representation of the mental model of an expert operator. Knowing the system context in which a task takes place is key to understanding how that task is performed, whether for troubleshooting or design. Not every system user is an expert, but having a model of expert knowledge can guide design of interfaces that support expert behavior in all users.

Work domain analysis also recognizes that there can be more than one human role involved in a work domain. While the different roles act in the same work domain, they may interact with and/or have responsibility over different aspects of the work domain. In this case, the different roles can be displayed as regions of responsibility in the abstraction hierarchy, where a region overlaid on the domain representation identifies the aspects of the domain for which one role is responsible (Figure 2). While the roles may have different areas of responsibility, they are assumed to work within the same work domain. Note in Figure 2 that the areas of responsibility overlap for the two roles. The fact that both roles are in the same work domain implies that they would interact to some degree, and the overlap between their responsibilities indicates parts of this work domain where they would interact. However, the nature of that interaction, whether one role influences or is subordinate to another, and the specific mechanisms of interaction are not represented.

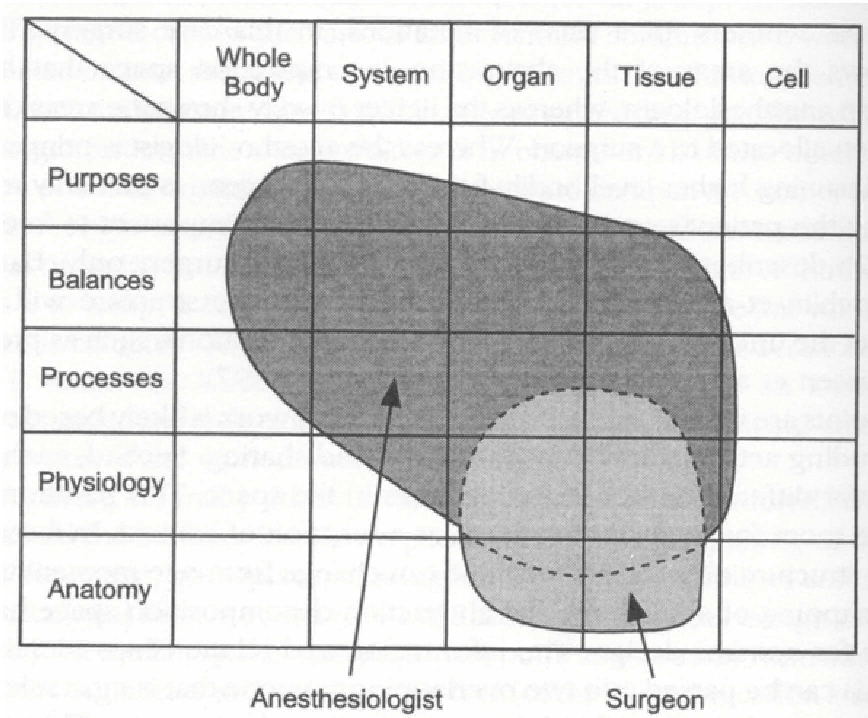


Figure 2 : Abstraction Hierarchy with Roles of Anesthesiologist and Surgeon, taken from Vicente, 1999, p. 258, originally from Hajdukiewicz, 1998 (Used with the author's permission)

Descriptions of how to make an abstraction hierarchy model through work domain analysis can be found in the books of Rasmussen et al (Rasmussen et al., 1994), and Vicente (Vicente, 1999). Table 2 lists some of the domains where work domain analysis has been applied, demonstrating its use in the design and evaluation of systems in many typically technological domains.

Table 2: Representative domains where work domain analysis has been applied

Domain	Purpose	Reference
Aviation	Cockpit display design	(Nadimian, Griffiths, & Burns, 2002)
Computer programming	Writing software specifications	(Leveson, 2000)
Emergency management center	Decision support	(Moray et al., 1992)
Higher education	Aligning pedagogical methods and technology with course content	(Dainoff et al., 2002)
Library information retrieval	Computer interface design for library patrons	(Rasmussen et al., 1994)
Manufacturing process control	Control system interface design	(Bisantz & Vicente, 1994)
Medical surgery	Structure data for patient monitoring	(Hajdukiewicz, Doyle, Milgram, Vicente, & Burns, 1998)
Military command and control	Command interface design	(Burns, Byrant, & Chalmers, 2000)
Military equipment procurement	Evaluation of proposed designs	(Naikar & Sanderson, 2001)
Virtual private network management	Problem solving interface design	(Kuo & Burns, 2000)

In summary, work domain analysis represents the structure of the environment in which work takes place, capturing the constraints placed on human behavior by the physical environment. However, this method does not examine the internal, cognitive constraints on the behavior of the humans in the system. Returning to Simon's illustration of the ant noted earlier, the environment is not the only constraint on the ant's behavior. The ant has internal rules to follow in a given situation based on instinct and experience, and selects which to implement. Work domain analysis can capture the environmental constraints, but other methods must be used to identify the internal cognitive constraints. Work domain analysis also identifies roles of agents in a work domain and generally what aspects of the domain in which the roles interact, but it does not describe the interactions between agents.

2.1.3.2 Control Task Analysis

Where work domain analysis captures the domain in which work takes place, other methods analyze the sequence of actions used to perform a task. One exemplar is control task analysis (Vicente, 1999), which captures the decision making and resultant actions that operate on that work domain. This analysis method does not result in a strict representation of the precise sequence of actions that take place. Except in highly deterministic work environments, the goals and intentions of individual humans will cause the sequence to vary around some norm or between a set of valid possibilities. As such, this method instead creates representations known as decision ladders (Rasmussen, 1976) that describe prototypical sequences of actions and decision making.

Decision ladders grew out of models of information processing following a typically linear sequence such as Norman’s seven stages of action (Norman, 1986). In these sequential models, human decision making and action are represented as passing through a sequence of events, typically beginning with perceiving a need to act in the environment, transitioning to a decision making stage to determine a course of action, and ending with execution of the action. During field studies, Rasmussen (1976) found that expert operators do not follow the pattern of behavior described in these sequential models. Instead, they opportunistically take shortcuts between elements of the sequence, skipping some sections and even moving backward through the sequence as afforded by their expertise with the system. This led Rasmussen to develop the decision ladder, which includes not only stages of perception and action from sequential information processing models, but also shunts and shortcuts where the operator can jump between stages in a non-linear fashion. An example decision ladder from the domain of process control can be found in Vicente, 1999, p. 198. As this type of model focuses on capturing the information processing that goes into to task performance, by definition it only examines cognitive constraints.

Control task analysis is not intended to describe the structure of the work domain, rather it captures typical actions that take place. Also, decision ladders do not represent the different levels of abstraction of a system, rather, they focus on actions to be performed related to information processing without showing how these relate to physical objects or ultimate goals. Work domain analysis and decision ladders should be seen as complimentary examinations of different aspects of the system (Burns & Vicente, 2001). Decision ladders have been applied to various domains including hospital operations (Rasmussen et al., 1994), library information retrieval (Vicente, 1999), and process control (Rasmussen et al., 1994; Vicente, 1999). Further information on how to perform a control task analysis can be found in (Vicente, 1999).

Models such as decision ladders may not be applicable to situations like education. Bainbridge applies the same criticism to decision ladder models as to sequential models of information processing in general. “Sequential models have difficulty with describing cognitive behavior in complex, dynamic environments, because this behavior does not occur in a set sequence" (Bainbridge, 1997, p. 357). In a constantly changing, complex environment, the human must be flexible and adapt their order and type of behavior to the current perceived conditions and predictions of upcoming conditions (Bainbridge, 1997). In education, where each student and instructor is unique and each classroom has a unique dynamic, decision ladders are not adequate to capture the full range of flexible, adaptive human behavior that is likely. Likewise, cognitive engineering representations of behavior have focused on specific activities such as monitoring and decision making; learning and teaching activities are not represented in the decision ladder.

Another aspect of decision ladders that makes them inappropriate for education is that they do not distinguish carefully between roles of agents. While it is recognized that different cognitive agents may perform the different actions in the model, the actions are not distinguished according to which agent performs them. "…control task analysis describes only what needs to be done, not how or who" (Vicente, 1999, p. 183). In evaluating education, it is necessary to distinguish the instructor and the student.

In summary, the scope of control task analysis spans the human's action sequences. The level of detail captured within this scope in a decision ladder is higher than that of the abstraction hierarchy as it examines individual actions and their sequence. In terms of the determinant of behavior, control task analysis is more focused on the requirements for task completion rather than the environmental constraints.

2.1.3.3 Hierarchical Task Analysis

Hierarchical task analysis is one method that falls under the general category of cognitive task analysis, and has been referred to as the "best known task analysis technique" (Kirwan & Ainsworth, 1992, p. 396). Cognitive task analysis is an umbrella term for many different techniques that extend "traditional task analysis techniques to yield information about the knowledge, thought processes and goal structures that underlie observable task performance" (Schraagen et al., 2000, p. 1). This focus shows that the focus is on cognitive constraints. An overview and review of cognitive task analysis is available in the report by Schraagen et al. (Schraagen et al., 2000).

The focus of hierarchical task analysis is similar to that of control task analysis, identifying the actions that are a part of a task. In hierarchical task analysis, the actions to be performed are decomposed in a hierarchical fashion from higher, very general actions to lower, very detailed actions (Shepherd, 1989). For example, the high level goal action "maintain the process" may be related to several elements at a lower level, including "monitor gauges," "adjust machine settings," and "record historical data." Several publications review methods for performing and representing hierarchical task analysis (e.g., Kirwan & Ainsworth, 1992 and Shepherd, 1989). It has been applied to numerous domains, including process control (e.g., Miller & Vicente, 2001). An example application to process control is seen in Figure 4.

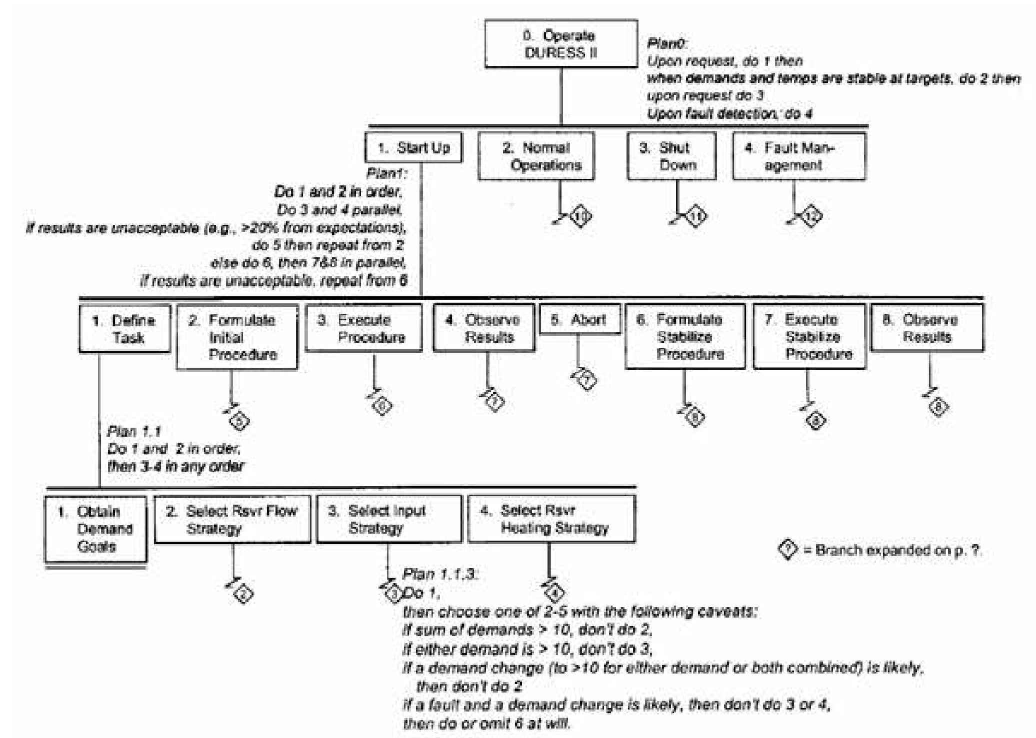


Figure 4 : Top level hierarchical task analysis of the DURESS II microworld process simulator, taken from (Miller & Vicente, 2001, p. 339) (Used with permission)

Like decision ladders, hierarchical task analysis models suffer from their sequential nature which prevents them from adequately capturing human behavior in a complex, dynamic task (Bainbridge, 1997). Hierarchical task analysis models are typically normative in that they represent procedures that are to be followed, as opposed to models based on work domain analysis and cognitive task analysis that can be used for descriptive and formative purposes. Thus, hierarchical task analysis is best applied to tasks where there are few opportunities for choice between actions. Hierarchical task analysis can produce very detailed representations because they are not limited to specific structures like decision ladders, so they can provide very general to very specific descriptions of actions and their sequences.

Unlike control task analysis, these actions are not represented explicitly in a model of the system or the environmental constraints; any relationship to the environment is only found, if provided at all, in the description of the action. In addition, as commonly represented in procedures, they tend to examine observable physical actions instead of internal, cognitive activities. Thus, the representation's scope is limited to physical actions and their immediate goals.

2.1.3.4 Comparison of Modeling Methods

Characteristics of each of these modeling methods are summarized in Table 3. It should be noted that there are no methods in cognitive engineering that examine both cognitive and environmental constraints and, correspondingly, both the environment of work and the actions of agents in that environment. Also, only work domain analysis distinguishes between roles, but assumes that the roles operate on the same work environment and does not describe how the roles interact.

Table 3: Comparison of Analysis Methods

	Work Domain Analysis	Control Task Analysis	Hierarchical Task Analysis
Constraints Examined	Environmental	Cognitive	Cognitive
Scope of Analysis	Environment where work takes place at different levels of abstraction	Actions and their sequence	Actions and their sequence
Examines Actions of Agents	No	Yes	Yes
Represents tasks sequentially	No	Partially – recognizes shortcuts taken in procedures, but focus is on the typical sequence	Yes - typically
Examines multiple agent roles	Identifies roles, but only in same work environment and without describing interactions between them	No – does not distinguish between roles	No – typically focuses on a single role

2.1.4 Application of Cognitive Engineering Methods

Cognitive engineering methods have been proposed and employed in a variety of ways for the design and evaluation of systems. The following are some examples of their application.

2.1.4.1 Ecological Interface Design

A major benefit of cognitive engineering has been the development and application of ecological interface design (EID) (Vicente & Rasmussen, 1992), a method which uses work domain analysis to design interfaces for controlling processes. In EID, a representation of the system is made through work domain analysis; this representation is then developed into an interface for the user. Measures of the system's performance are integrated into the interface so they are presented in the context of the model. Interfaces created with EID are capable of describing the system at different levels of abstraction so the operator can shift fluidly between these levels when monitoring and troubleshooting the system (Burns, 2000).

An early study using EID compared performance of subjects on a fault diagnosis task in a process control microworld simulation. The results showed that subjects who used an interface designed to represent the physical and functional levels of the abstraction hierarchy performed better than those who used an interface designed only from physical aspects of the system (Vicente & Rasmussen, 1992). This implies that the added representation of the functional level assisted the fault diagnosis task. A separate study confirmed this result, finding that performance on trials with faults was better using the interface with physical and functional information than an interface only using physical information (Vicente et al., 1995). This study also found that subjects who had the most effective diagnosis performance typically started troubleshooting at the highest levels of abstraction and moved toward the lowest. A study by Janzen and Vicente found that when all subjects were given an ecological interface, those that used the functional information more frequently and efficiently had better performance on diagnosing faults than those who did not, again suggesting the advantage of this representation (Janzen & Vicente, 1998). A review by Vicente of studies using EID found that these interfaces are associated with improved performance when diagnosing faults, but show no statistical difference in performance during normal operation (Vicente, 2002).

There are two conceptual advantages to using EID (and therefore work domain analysis) in the design of interfaces. First, the abstraction hierarchy provides a comprehensive representation of the system at all levels of abstraction, thus identifying the elements of the system that an expert operator needs to know. These elements must be included in the interface to support operators, especially during abnormal operation. Second, the formal process of work domain analysis encourages the modeler to create an explicit, complete, and detailed representation of the system. During this process, the modeler's own internal mental model may be challenged and improved.

A review of EID and the various domains where it has been successfully applied can be found in (Vicente, 2002).

2.1.4.2 Curriculum Design and Evaluation

Another application of cognitive engineering, which has been mentioned previously, is the design of curricula for worker training and for higher education. Lintern and Naikar (1998) describe how work domain analysis and an analysis of action using decision ladders can be used to identify the training needs for a task by representing the important aspects of the environment and the prototypical action sequences. The identified training needs can then be used to guide development of a training system. For example, Naikar and Sanderson (1999) have used work domain analysis to describe the work domain of operating a military fighter aircraft, and then used this description to create functional specifications for a training system.

In higher education, Dainoff et al. (2002) described a curriculum in psychology with the abstraction hierarchy for the ultimate purpose of evaluation based on the model. Dainoff et al. see the work domain as the course content to be taught, so that the content is decomposed from a high level concept to particular functioning of that concept down to individual, real-world observations of the concept. As in the training applications above, work domain analysis is used to represent the curriculum to be taught or trained, but not the system of education. Dainoff et al. also represent the pedagogical methods used as an aspect of the work environment in a separate abstraction hierarchy. This separates the content from the methods used to teach it, rather than relating the content with methods and actions and relating both to the overall goals of the system. While this addresses part of the educational system, it is not a comprehensive representation of teaching and learning processes.

2.2 Education

2.2.1 Definition

Merriam-Webster's Online dictionary definitions for "educate" include "to develop mentally, morally, or aesthetically especially by instruction;" and "to train by formal instruction and supervised practice especially in a skill, trade, or profession" (Merriam-Webster, 2004). Education is defined as "the action or process of educating." Two major roles emerge from these definitions: the student and the instructor. In education there is necessarily at least one person whose primary function is learning (the student) and at least one person whose primary function is teaching, training, supervising, or instructing (the instructor). As both roles are described as integral to education, an effective education system comes from both effective teaching and effective learning, and research must examine both to improve the whole system of education. This is reflected in the structure of the recent National Research Council report on learning where one major section of the report is dedicated to students and learning and another is dedicated to instructors and teaching (Bransford, Brown, & Cocking, 2000). This does not preclude other roles in education such as teaching assistants, administrators, librarians, etc.

Brown observes that one of the significant characteristics of education is that it is a complex and highly interrelated domain, where learning takes place through a variety of activities that build on each other (Brown, 1992). Although elements in education are often examined and applied as though they were independent, they should be treated as interacting parts of a system:

> "Classroom life is synergistic: Aspects of it that are often treated independently … actually form part of a systemic whole. Just as it is impossible to change one aspect of the system without creating perturbations in others, so too it is difficult to study any one aspect independently of the whole operating system." (Brown, 1992, p. 179-180).

Thus, approaches to education and educational research must take a system perspective, examining both individual elements of the system and how they interact. This is also recognized by the Center for the Advancement of Scholarship on Engineering Education (a part of the National Academy of Engineering), which is concerned with research on "how curricula, instructional materials, and teaching practices interact to affect learning" (CASEE, 2004). This type of research requires a systems focus.

2.2.2 Education and Action

Another aspect of these definitions of education is the implication that action is a central aspect of education. Education is defined as the act of educating, and educating, according to the definitions, involves the actions of development (by the student) and training (by the instructor). The centrality of action to education is further supported by the nature of Bloom's taxonomy of educational objectives (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956), which is based on the type of actions students should be able to perform. Even in one of the educational situations where students may be passive, a traditional lecture, the instructor is engaging in the activity of lecturing, and students must attend to the lecture for any learning to take place.

There are two types of action that are important to education: cognitive and physical. Cognitive activities are the activities that take place in the arena of the brain/mind. These are engaged in as part of teaching and learning and typically cannot be directly measured. Again, referring to Bloom's taxonomy (Bloom et al., 1956), which is explicitly described as being designed for the "cognitive domain," each category describes a type of cognitive activity characteristic of a category of objective. For example, Knowledge objectives are described as "emphasiz[ing] most the psychological processes of remembering" (Bloom et al., 1956, p. 205). The definition of cognitive activity used here is purposefully broad since the exact nature and scope of cognitive activities may vary between WAA models based on the scope of the particular system they examine and the purpose of the analysis. It is not possible to develop a comprehensive list of cognitive activities since as new pedagogies and theories of cognition develop, new cognitive activities that take place during learning will be identified. Physical actions are the manual tasks students and instructors engage in and are typically directly observable.

In education, students are assigned physical actions so that they will engage in the desired cognitive activities. For example, a student cannot learn a fact without first at least reading or hearing that fact once. Physical actions are necessarily associated with cognitive activities, though any of several sets of physical actions may correspond to a cognitive activity. Examples of cognitive activities and associated physical actions are given in Table 4.

Table 4: Example Cognitive Activities with Associated Physical Actions

Cognitive Activity	Physical Action
Memorization	Take notes during lecture, read and rehearse notes, read textbook
Feedback	Work assigned problems, examine corrected work
Pattern Recognition	Attend lecture, work example problems, search for similar instances in assigned problems
Apply Concepts to Analyze Designs	Review course material, identify designs for analysis, document work

This distinction and connection between cognitive activities and physical action is seen in many educational approaches. One model of cognition that has been used to build tutoring systems is ACT-R (Anderson & Lebiere, 1998). The ACT family of models view humans as having a set of production rules, which are essentially cognitive transformations of ideas. Students learn these production rules through physical practice on exercises that require using them, and a number of tutoring systems have been built based on this theory (Anderson, Corbett, Koedinger, & Pelletier, 1995). Likewise, the constructionist approach to education (Papert, 1991) involves students constructing their own knowledge (a cognitive activity) through building a meaningful, often physical, artifact (requiring physical action) (Harel & Papert, 1990).

2.2.3 Evaluation

Evaluation is necessary for any system to ensure it is meeting or has met its stated goals. "Evaluation in the context of educational systems is briefly defined as examining the effectiveness of an educational system (or component of that system) in meeting learning and teaching goals" (Nickles et al., 2001). Without evaluation it is impossible to judge how well a system is performing or how to make improvements to it.

In education, evaluation activities may be performed by the instructor, by a trained evaluator, or by the two working in conjunction. Each person has advantages when performing an evaluation. The instructor typically has a better knowledge of how the course works and what needs to be taught, but may not be skilled in evaluation techniques. The trained evaluator may not know the content of the course, but will have skill in evaluation techniques and take a more comprehensive look at the system due to this training. It should also be noted that there may also be a course designer role, separate from the evaluator and instructor. This role may or may not carry out planning evaluation activities. While in many cases all three roles are held by the same person, the roles of instructor and evaluator will be distinguished in this dissertation. For the purposes of this dissertation, it is assumed that the instructor designs and teaches the course and that the evaluator performs all evaluation activities for the course, including planning, formative, and summative. The exception to this is when instructors are specifically spoken of as also having the role of the evaluator.

One consideration in evaluation is alignment. The concept of alignment involves determining if the content, teaching methods, and assessment methods are appropriate or not in light of the educational goals (based on Biggs, 1996). This concern with alignment has also been expressed as taking a systems perspective on an education program; that is, examining how the various parts of the system support the goals (Brown & Campione, 1996). The concept of alignment in evaluation points out that taking measurements alone is not sufficient for truly examining the effectiveness of a system; rather, evaluation must be done in light of the structure of the system. Also, alignment in a system design does not mean the system is guaranteed to succeed as the elements of the system can be carried out poorly. Alignment only implies that if the identified means to achieve the goals are successful, the goals should be met.

Several different types of education evaluation can be performed, defined by their purpose and the point in the system's life cycle in which they are made. *Planning evaluation* is performed during curriculum and course design. "The purpose of a Planning Evaluation is to assess understanding of a project's goals, objectives, strategies, and timelines" (Stevens et al., 1993, p. 4). This is partly to validate the system against known educational theory and best practices, and should also examine how well the goals are aligned with the strategies (see Bransford et al., 2000, p.151-152). Preferably, planning evaluation will examine the entire system before it is implemented. As noted above, determining how well the design of an educational system is aligned is one key activity of planning evaluation. When it is performed for a single course, typically the instructor performs the planning evaluation. This type of evaluation is not widespread in practice (Flagg, 1990; Stevens et al., 1993), and when it is performed it may be included with formative evaluation (which will be discussed below).

Summative evaluation occurs at the completion of units of instruction, e.g., through student surveys and a final exam at the end of a course and exit surveys and interviews at the end of a degree program. Summative evaluation provides a high-level assessment of the efficacy of the system under study (Stevens et al., 1993). Many measurements used in engineering education can be directed for use in summative evaluation, most notably end of course surveys, when used to examine a single course.

The purposes of summative evaluation are to judge the effectiveness of the system in meeting pre-set goals and, in some cases, to determine whether or not to continue the system in the future. A summative evaluation is not necessarily comprehensive, and may focus on selected aspects of a course such as specific ABET criteria. The course instructor may or may not be involved in this evaluation.

In addition to examining the design of the system beforehand and its effectiveness afterward, the educational system can be evaluated as it is in progress to determine what improvements can be made. Continuous improvement requires instructors to adapt their instruction through several mechanisms, such as changes in presentation of material, changes in instructional methods and pedagogy, changes in course administration, and changes in their methods of grading student assignments. This third type of evaluation is commonly called *formative evaluation*, where instructors are able to make an informed interpretation about the efficacy of their instruction in time to benefit their current students (Walker, 1997). While formative evaluation here is defined to take place during the use of the system, others have defined it to include planning evaluation as well (Flagg, 1990). Alignment must also be a part of formative evaluation in that the activities cannot simply be assessed in isolation, but instead by how well they help students learn course related information in ways that support the course goals (Bransford et al., 2000).

Formative evaluation can take different forms. Instructors regularly perform informal, opportunistic formative evaluation based on data sources such as apparent student attentiveness in lecture and the nature of the questions asked by students. Instructors also assess student learning through assignments such as homework and tests throughout the course and use this for formative evaluation. Formative evaluation can also bring in outside evaluators to videotape a lecture and critique it or interview focus groups of students.

In relation to the quality of formative evaluation methods, Smith (Smith, 2001) observes that there is relatively little research on improving methods for formative evaluation, and work needs to be done to examine the effectiveness of such methods.

2.2.4 Evaluation in Engineering Education

A survey was conducted in 2000 to examine current evaluation practices among engineering instructors (Nickles et al., 2001). The following is a summary of the results of this survey. Due to a variety of uses of the term evaluation and assessment amongst the surveyed population, the term “critique” was used in this survey to describe evaluation activities and will be used here in reporting on this survey.

2.2.4.1 Number of Responses and Demographics

Analysis was conducted on 219 responses to the survey. A total of 230 responses were collected, with 11 removed from the data set as they identified themselves as not being an instructor in an engineering or science field. Of the respondents who provided demographic information, 109 are full professors, 51 are associate professors, 33 are assistant professors, and 25 hold other academic ranks. Years of teaching experience range from one to 50 with a mean of 18.3. Percentage of time dedicated to instruction ranges from 5% to 100% (two responders answered with values over 100%) with a mean of 47.2%. The average number of students per class ranges from 5 to 250 with a mean of 39.0. Of all responses, 56.4% reported being a member of a committee or organization focused on improving education. Responses were received from a wide variety of engineering and science disciplines and institutions in the United States. Two responses came from institutions outside the United States. Due to a technical error, no data regarding the number of courses taught per term or tenure status were recorded.

2.2.4.2 General Course Evaluation

The number of times a course is critiqued during a single semester ranged from zero to more than three and averaged 1.77 times. Only 2% of the respondents stated they performed no critiquing during the term. The methods used to critique courses and their frequency of use are shown in Figure 5. (Multiple selections were possible.) The vast majority use the evaluation survey provided by the institution, while self-generated tools are used much less frequently. Only 4.5% of instructors use evaluation by an outsider, even though many institutions have an evaluation center offering this service. Also, no method besides the institute-provided survey was used by more than half of the respondents. Thus, one sees an under-utilization (and possibly a lack of awareness) of the evaluation methods and measures available to instructors.

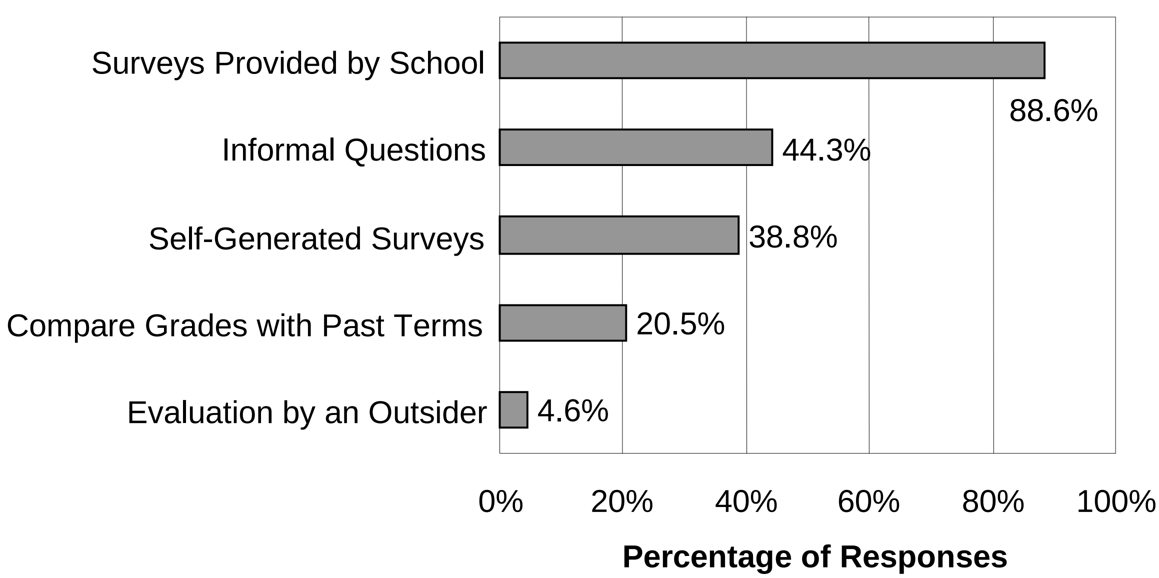


Figure 5 : Critiquing methods used

Respondents reported that 96.8% of them have made changes to a course based on critique results. The changes made to courses based on a critique are shown in Figure 6; due to a technical error, no data was collected regarding changes to exams. These results are encouraging as they suggest that many instructors are completing the cycle from measurement to analysis to change, and thereby using evaluation as a mechanism to improve instruction. This question did not specify whether changes were made to the current course or future courses.

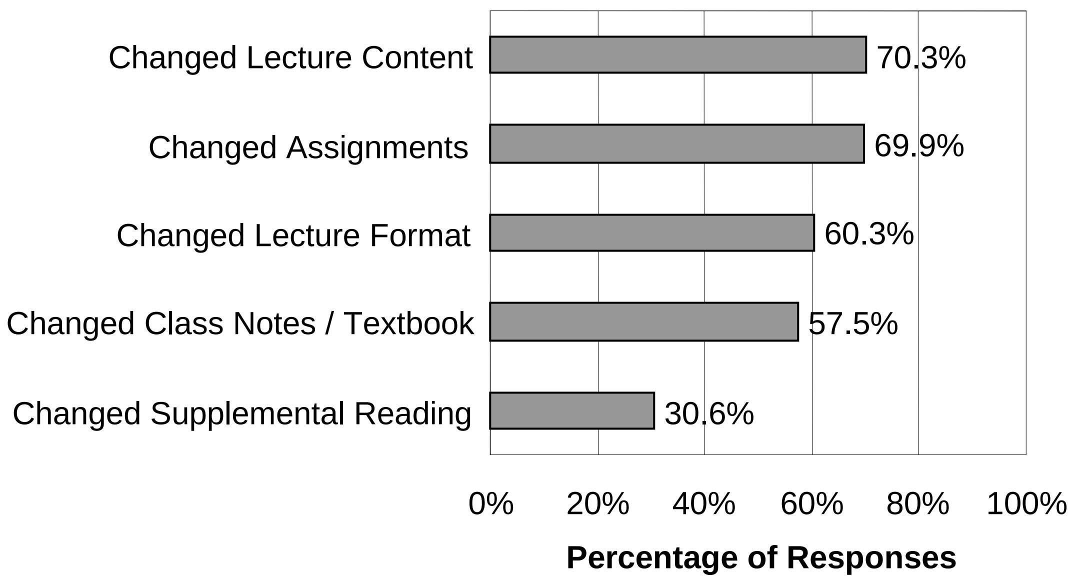


Figure 6 : Changes made based on a critique

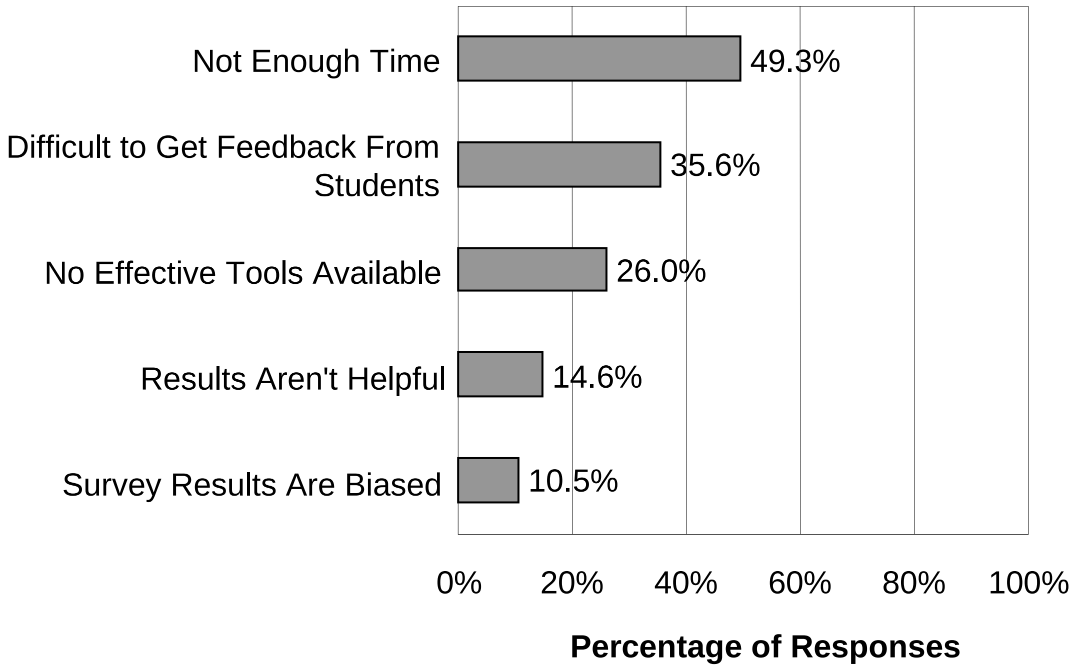


Figure 7 : Factors that hinder critiquing

Factors that instructors reported as hindering critiquing are shown in Figure 7. Each of these factors presents a separate challenge. The first is providing a mechanism that takes little time on the instructors' part to administer, their greatest concern. Difficulty in getting feedback and biased results are related and may stem from several perceptions: that students find evaluative activities too time-consuming; that students will not participate to compliment but rather to complain, providing a one-sided view; and that students' comments are inherently biased due to their specific viewpoint. The respondents who indicated a lack of effective evaluation tools may either not be aware of tools or have specialized needs. The problems with results not being helpful may stem from a lack of evaluation skill, from evaluation tools that do not provide adequate explanation, or from results that highlight problems over suggesting improvements.

Related free-response comments reflected a wide variety of opinions. Some suggested that instructors may perform evaluations as a trial-and-error process. For example, one respondent noted "I have made changes in everything, but it has not been scientific. It has just been by 'feel.'" Three respondents believed they did not know enough about evaluation to conduct one. Also, three respondents indicated a desire to reduce the work required of the students by evaluative activities.

2.2.4.3 Evaluation of Internet Course Materials

Of all respondents, 74.0% reported using some aspect of the Internet in their classes. Complete results of the use of the Internet in courses are detailed in Figure 8.

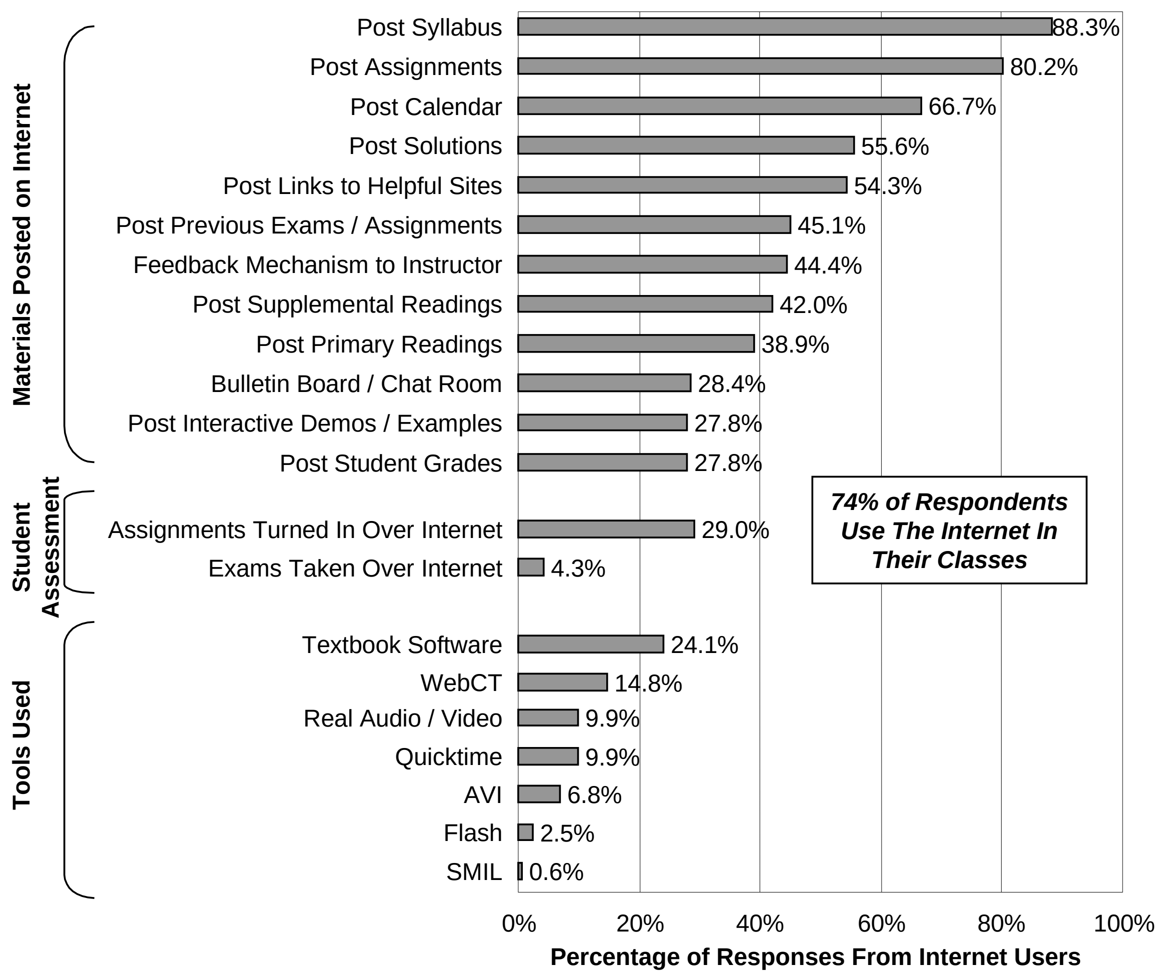


Figure 8 : Use of the Internet in instruction

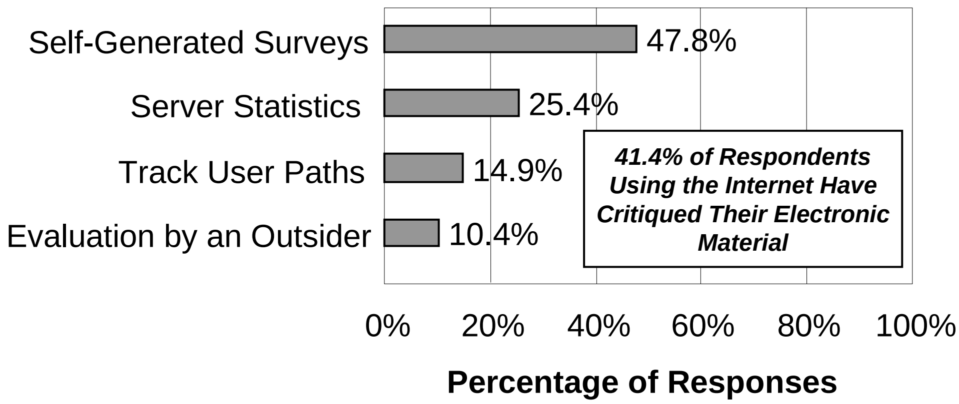


Figure 9 : Evaluation tools used with electronic educational material

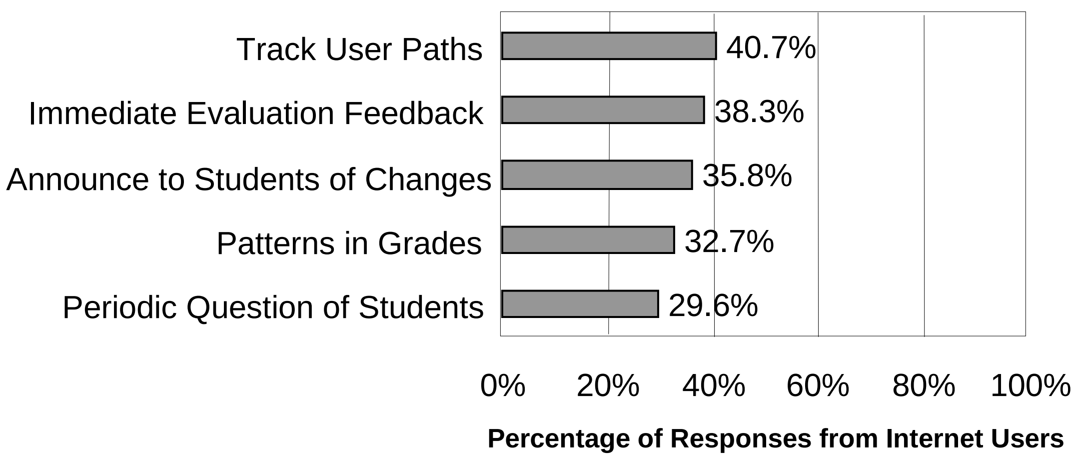


Figure 10 : Evaluation tools desired for electronic educational material

In regards to evaluation, 41.4% of respondents who use the Internet said they have evaluated their electronic educational material. One respondent commented "surely everyone 'critiques' their attempts to use the internet [sic], as well as everything else." In fact, less than half reported doing so, a substantial drop from the percentage of instructors who report evaluating their normal classroom instruction. The tools used for evaluation of electronic material are shown in Figure 9. The evaluation tools desired by all respondents who use the Internet in their courses are shown in Figure 10.

2.2.4.4 Reasons Reported For Not Using the Internet

The reasons why some respondents reported not using the Internet in instruction are shown in Figure 11. Some of the reasons are comparatively mundane, including time-constraints and technical resources. Over one-third of the respondents also indicated doubts about pedagogical benefits to instruction through Internet usage.

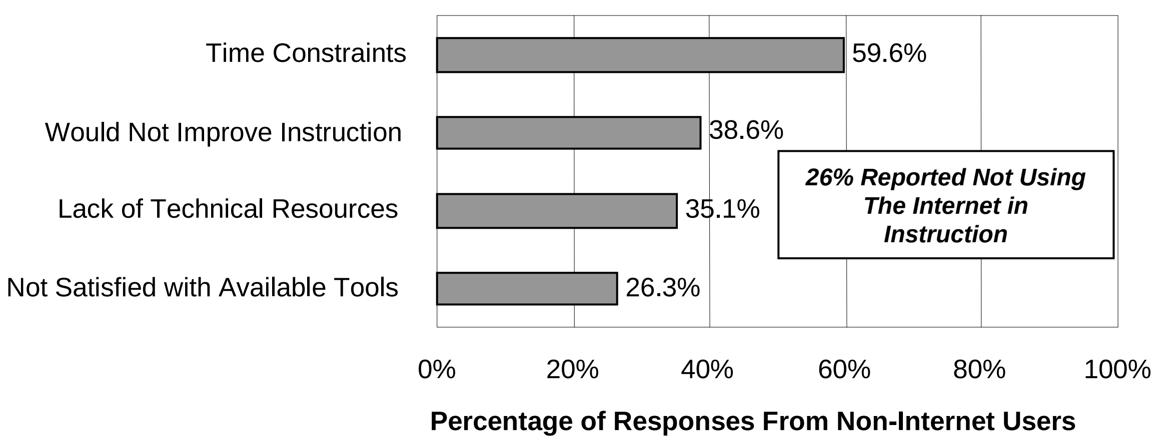


Figure 11 : Reasons for not using the Internet

2.2.5 Measures of Education

Building on distinctions used in measures of human integrated systems (Gawron, 2000), measures of education can be categorized into one of three groups based on the aspect of education they are intended to measure: performance, process, and perception. For example, a distinction has been made between performance and process measures in describing how to measure aspects of human visual inspection; whether by how well the inspector performed (e.g., number of defects detected) or by how the inspector carried out the process (e.g., measuring eye movements during inspection) (Megaw & Richardson, 1979; Nickles, Melloy, & Gramopadhye, 2003). Also, measures of a student's perception of their learning experience are very common in educational research (Gay & Airasian, 2000). These three categories are described in greater detail below along with descriptions of how these measures may be collected by a CMS.

2.2.5.1 Performance Measures

Performance measures in education are defined here as assessments of student learning. Most university courses have assessments in the form of homework, quizzes, tests, projects, and/or other graded assignments. These will be referred to as assignments, though it is here acknowledged that they are a type of assessment. Besides these, non-graded assessments can be used for formative evaluation such as the classroom assessment techniques provided by Angelo and Cross (Angelo & Cross, 1993). Assessments are a natural component of normal instruction. However, performance measures can be more an indication of student motivation than of the quality of instruction; for example, students may work hard to overcome poor instruction in order achieve a desired grade, thus masking insight through these measures alone. Comparing grades between instructors can also be difficult, as the types of assignments and grading mechanisms may vary widely. Finally, unless interim assignments are given, assignments often only provide data at the conclusion of instruction on specific concepts, reducing the extent to which remedial interventions can be given following poor performance. These problems can be mitigated somewhat by administering assessments immediately after lecture and lab, by completing on-line reading or demonstrations, and by using electronic, in class tools (Brophy, Norris, Nichols, & Jansen, 2003). However, in keeping with Brown's system view of education (Brown, 1992), student reading, reflection on material, and experience in applying concepts can be important components of learning, reducing the extent to which immediate quizzes predict final student performance.

Administering a performance measurement can be a time consuming process as the evaluator must create the assessment, distribute and collect student responses, and score and analyze the results. Internet-based tools that allow evaluators to distribute and, depending on the design of the assessment, automatically score an assessment significantly reduce this administrative burden. A number of these exist, either as part of an existing CMS such as in WebCT or Blackboard (Siekmann, 2001) or as a standalone component such as WebAssign (Brawner, 2000). For these web-based assessments, students are required to visit the web page for the assessment or, in the case of a CMS, the system can initiate a pop-up browser window containing the assessment based on criteria such as time limits or events during the student interaction with the system. These performance assessments can be graded assignments or anonymous non-graded assessments.

2.2.5.2 Perception Measures

Perception measures capture student opinions about their learning and can be acquired through several means including focus groups and surveys. These measures may examine the information channel through which students learn, the utility of educational materials, and students' perceptions of their achievement of the content. Anonymous surveys have a significant advantage in that they allow students to express honest opinions without their responses impacting the instructor's perception of them. Surveys can be administered at any time during a course and can address questions at various levels of granularity. That is, surveys can examine the students' opinions of how well the course goals are achieved overall and how much an individual intervention helped them learn a single concept.

While perception measures do not directly measure learning, they can provide insight into what students find difficult and the mental processes they are using to learn. However, students often have a limited viewpoint and specific goal set, reflected as biases in their perception measures (e.g. complaints about workload can create a halo effect in their comments on the quality of instruction) and as limitations on their ability to perceive how much they actually understand the course concepts (e.g. students may not be aware of what they do not yet know, or they may recognize that they are not yet professionally competent without awareness that they are meeting the goals for a course). Even so, many studies have shown student evaluations to generally be reliable and valid assessments of teaching, especially as part of summative evaluations (Felder, 1992).

As with assessments, web-based tools can reduce the evaluator's time spent administering surveys. Surveys can use the same tools that are available for assessments and can be delivered anonymously with quick-to-complete, frequent requests for responses suitable for formative evaluation. Survey questions with a rating scale can be automatically scored; free responses from students, such as requests for suggestions, can be reported verbatim to the evaluator.

2.2.5.3 Process Measures

Process measures can be collected about the types and duration of student learning activities. These measures capture data describing physically observable actions and are often very detailed in the type and amount of data collected. Evaluators often have expectations for what activities students should engage in, and how they should engage in them so that they will learn. As such, in analyzing these measures a relationship is usually assumed between performing the specified actions and learning the content. Process measures can determine the accuracy of these assumptions and whether they are being met.

The relationship between performance and process measures is not consistent. In considering this relationship, the ecological approach of cognitive engineering emphasizes the necessity of considering the context, i.e., the structure of the environment and goals of the system. The context of the system can vary between courses, students, instructors, and institutions. For example, studies correlating electronic logs of interaction with software with performance measures have shown somewhat mixed results. In some cases, the log data are useful in predicting student learning. In one study, an educational website that teaches children to program collected a log of student interactions with the software (Bruckman, Jensen, & DeBonte, 2002). The log recorded the activity of students and indicated the amount of time spent on task. It was found that time on task in programming, as determined from the interaction log, is significantly positively correlated with programming performance. Another study showed that university students who actively used an online study tool before exams had higher scores on the exams than those who did not use the tool (Grabe & Sigler, 2002). An exploratory study that examined various factors that could impact on-line learning found a strong correlation between the total number of hits on the course website from individual students and their average grade for the course (Comunale, Sexton, & Voss, 2001-2002). In this study, students were only able to access certain information through the Web-based module and their use was timed by a login function. A controlled study of student interaction with a Web-based learning module showed that time on task was a strong predictor of student learning (Taraban, Rynearson, & Stalcup, 2001).

However, not all studies are so clear in linking logs of activity and performance. In the study by Comunale, et al. noted above, a regression analysis included total number of hits within the website as the main explanatory variable for the average grade for one course; however, individuals' GPA information was lacking for this course and was the major factor in a regression analysis of another course that was studied. One study examined both data across the whole course and divided the data for the course into three time periods corresponding to the three exams (McNulty, Halama, Dauzvardis, & Espiritu, 2000). When examining data for the Web Forum section of the website in aggregate, it was found that among the 1/3 of the students with the highest grades, there was a positive correlation between number of visits and final grade in the course, while no such correlation was found in the 1/3 of the students with the lowest grades. However, when the average length of each visit made on the website during each of the three time periods was compared to grades on the corresponding exams, there was a strong negative correlation for the first exam and a moderate negative correlation for the second. In other words, students with longer visits tended to have lower grades on the first two exams. While this appears to contradict the typical time on task assumption, it may indicate that the system was poorly designed or that using the system is not the essential learning activity. Instead, the system may provide information necessary for the more important learning activity that takes place off-line.

Historically, these measures could be difficult to collect, as they often required students to self-report their course-related activities (e.g., time cards), which added both a level of subjectivity and a data collection and entry burden on the evaluator. For example, an ethnographic study on communication in student teams required the investigator to attend classes and group meetings with the team and to request records of all messages passed between team members (Turns, 1998).

When some or all aspects of a course are administered by a CMS (e.g., distribution of instructional material, assignment and collection of student assignments, and recording and releasing grades to students), students' access to these aspects of the course could be measured in detail, and collected and analyzed automatically through web server logs. These logs capture all student access to files and, when coupled with a login system, could track the behavior of individual students. If the context in which these actions are made is represented in a model, student behavior could be interpreted in light of that representation. For example, the timing of student access to learning material relative to lectures and homework assignments could provide insight into student preparation before lecture and the time spent on assignments.

A significant advantage of a tool that analyzes web server logs is that data collection and analysis can be done automatically, requiring no effort from students besides their normal use of the web site, and requiring no effort from the evaluator other than examining the results. Data from web server logs have been used in various ways. Commercial websites have used them in conjunction with demographic data to examine patterns of interaction by different groups of users (Nicholas, Huntington, Lievesley, & Wasti, 2000). Web server logs have also been used to examine patterns of user navigation through a website to evaluate the usability of those sites, especially with respect to site navigation (Paliouras, Papatheodorou, Karkaletsis, Spyropoulos, & Tzitziras, 1999; Randolph, Murphy, & Ruch, 2002). While data from server logs is useful in its own right, some have suggested the utility of coupling them with other forms of data (Hochheiser & Shneiderman, 1999; Ingram, 1999-2000). Ingram suggests using the logs in conjunction with surveys and assessments to examine the effectiveness of the site for learning. He also suggests using interviews in conjunction with the data to support usability studies. Further, he suggests that server logs can serve as a means of confirming usability studies in that the results of a usability study of an existing design can be compared to use by the whole current population of users via the server logs. Both Ingram and Hochheiser and Shneiderman note that market research can also be used for commercial sites, examining customer patterns of navigation that lead to sales. Both sets of authors also note that the goals of the site must be considered when analyzing server log data. While a number of general software tools exist to present statistics on web server logs, there are no tools that analyze web server logs for educational evaluation purposes, and correspondingly no tools that integrate process measures from web server logs with performance measures suitable for comprehensive formative evaluation.

2.2.5.4 Measurement Validity

The validity of a measurement is an important consideration when using it in any evaluation. Tronchim has defined high validity in general as "[t]he best available approximation of the truth of a given proposition, inference, or conclusion" (Trochim, 2001, p. 353). Validity with respect to measurement has been defined in a number of ways. Blood defines validity as "the consistency with which an instrument measures the variable or variables it was designed to measure" (Blood & Budd, 1972). The definition used here for measurement validity is from a National Science Foundation publication on educational evaluation: validity is "[t]he soundness of the use and interpretation of a measure" (Stevens et al, 1993, p. 97).

Measurements that make the best approximation to truth are clearly most desirable, as they will most accurately indicate the actual state of what they measure. However, many constraints prevent the use of measures with the highest possible level of validity. Flagg identifies two of the major constraints as time and money (Flagg, 1990). Time is required to search for or develop measurements of high validity. Funding limitations can restrict the personnel (and level of expertise) available to develop and administer a measure and the number of subjects that can be used in development or implementation. Flagg also notes that these constraints are typically more restrictive on formative evaluation (Flagg, 1990). When an educational system is in operation, typically most of the financial resources are budgeted for immediate operational needs, not for evaluation. Also, the time required of both instructors and students for the various aspects of a course limits the time available to develop and administer highly valid measures in time to be useful in the course. In the survey discussed earlier, engineering instructors reported that the factor that most hinders them from performing evaluations is the lack of time available to do so. Thus, while highly valid measures are most desirable, pragmatic factors may require the use of measures of less or unknown validity that can provide timely insight, particularly in formative evaluation.

The validity of a measurement also depends on the context in which it is applied and the extent to which the evaluator can understand the impact of this context on its meaning. Again, the ecological approach recognizes the influence of the environment on the performance of a task. The influence of the environment includes making certain interactions with the system essential in one context but irrelevant or harmful in another.

Examples of the interaction of validity and context can be found in the process measures of learning through computer interaction as reviewed above. Time on task is recognized as a reliable measure of student learning, so that the amount of time spent by a student engaged in a learning activity is proportionate to the degree of learning that takes place due to that activity (Taraban et al., 2001). The studies reviewed above show that measures of time on task on a computer learning activity based on interactions with the computer can potentially be validated as measures of learning. However, the McNulty et al. study (McNulty et al., 2000) shows that not every measure of interaction holds to the time on task assumption.

The following thought experiment also shows the interaction of validity and context when measuring learning through computer interaction. Assume there are two undergraduate courses, each with its own website. The instructor of the first course only uses the website to post notes, handouts, and assignments for students to access. The instructor of the second course posts required virtual laboratory assignments that can only be performed on the course website. As students must log in to access the material for either class, interaction with both websites is recorded in detail.

In the case of the first course, student's interactions with the website will generally involve visiting the website occasionally to access the material. Students may do several things with this content, including reading it on-line, downloading it to view off-line, print it to hardcopy, or a combination of these. In addition, students may organize into groups where one person acquires the content and gives copies to the other students. In any case, the student interacts with the website to access the content, but no reliable measure can then be made based on the web server logs of how students read and study the material. Also, since students can make copies to study later or to give to others, the web server log cannot exactly measure exact times and for how long students examine the material.

Students in the second course will exhibit a very different pattern of interactions with the website. Since the virtual laboratory assignments are required and must be completed on-line, students will access them and perform the work on-line. Time on task measures for individual students can be extracted from the interaction data including time spent interacting with the virtual laboratory (estimated by start and stop times) and total number of requests to the server for files within the virtual laboratory. These data give an accurate measure of the time students spent engaged with the virtual laboratory, which can serve as a measure of learning. Unlike the first class, learning must take place on-line and the time spent in this activity can be measured.

2.3 Applying Cognitive Engineering to Educational Evaluation

During the formation of the discipline of cognitive engineering, practitioners considered how to apply it to education; however, true applications have been limited compared to other domains. One of the earliest calls for a discipline of cognitive engineering included observations on how it could be applied to education, though it was not applied at the time (Norman, 1980). Pejtersen and Rasmussen considered how cognitive engineering methods can be applied to work domains where learning is involved in some way, though not directly to the domain of education (Pejtersen & Rasmussen, 1997). With respect to the task to be trained, work domain analysis has been used to provide a full description of the domain of work that is to be trained (Lintern & Naikar, 2000). The advantage of this is that the training program can be designed to teach all the applicable levels of abstraction of the domain necessary for expert performance. This is in line with current directions in education that focus on the knowledge of experts and its implications for the content and methods of education (see chapter two of Bransford et al., 2000).

Dorneich (2002) used work domain analysis to model some general components of the software architecture of a training system. Here, the software was considered the domain in which the humans (students) act. Though Dorneich does not use the term planning evaluation, he describes the abstraction hierarchy being used in such a way:

> "It is through careful articulation of the [abstraction hierarchy] that the features, instructional pedagogies, and collaboration aspects of the elements of [the training software] are designed in a principled way. Gaps in the [abstraction hierarchy] (missing links in either direction) identify gaps in [the software's] ability to realize the stated functional purposes [goals], and leads the developer to revise and iterate the design"(Dorneich, 2002, p. 206).

Dorneich recognizes the needs of different roles of people that may interact with the software, but these needs are not explicitly separated by role in the model. Also, the lowest level of "physical objects" describes software modules rather than what are typically considered physical objects, thus a different name is needed. In addition, the interactions of humans and the software are not included in the analysis, only points at which the human may interact with the software. Dorneich clearly states that the abstraction hierarchy is used to describe the training software, which is only one entity in the entire system of learning.

Recently, Dainoff et al. asserted that “the process of education and training can be considered a complex sociotechnical system” and thus can be examined by the methods of cognitive engineering (Dainoff et al., 2002, p. 825). This would include using cognitive engineering methods to aid the design and evaluation of a system of education. Dainoff et al. do not present an argument that education is a complex sociotechnical system, but an argument is made here. By definition, education involves multiple humans in two different roles, instructor and student, and so is necessarily social. Also, technology has always been a part of education from the clay tablet to paper to the CMS. In addition, education can be argued to be qualitatively high in at least four of the eleven characteristics of complexity listed by Vicente (1999). First, education can involve large problem spaces in that instructors and students can typically choose from a wide variety of actions to accomplish goals. Second, as noted earlier, education is necessarily social due to interaction between instructor and student, and is often even more so due to team teaching and learning activities. Third, students and instructors tend to come from a variety of backgrounds, thus bringing many heterogeneous perspectives to teaching and learning. Fourth, as noted above, Brown (1992) points out that education is coupled, i.e., that the parts cannot be separated and examined in isolation.

Dainoff et al. apply the cognitive engineering method of work domain analysis to both the content to be learned and pedagogical methods used in an undergraduate psychology course (Dainoff et al., 2002). While they state that this analysis is performed to examine the alignment of the pedagogical methods and the course content, and will eventually be used for evaluation of the educational system, how it will be used for evaluation is not described. While a pedagogical approach is captured by these authors, it is not clear how the representation of the pedagogical approach is related to the representation of the course content so they can be aligned. In addition, this work does not represent actions which can be evaluated. As will be discussed next in chapter three, this dissertation asserts that actions and their corresponding cognitive constraints are necessary for representations providing both sufficient scope and detail for rigorous planning and formative evaluation.

Likewise, this work does not explicitly recognize the roles of the student and the instructor. Work domain analysis has been used to examine the roles of humans to some extent in terms of identifying separate but parallel domains for those humans (Rasmussen et al., 1994, p. 262), or separate areas of responsibility in achieving the same goals in the same work domain (Vicente, 1999, p. 258). In education, more than one distinct role needs to be recognized; while each has its own set of goals and actions; their intrinsic coupling requires that they can not be modeled completely independently.

In considering the suggestions of Pejetersen and Rasmussen (1997) with respect to learning situations, the benefits of work domain analysis should be maintained. Work domain analysis is able to model the domain of the work environment and model the applicable levels of abstraction. However, since it cannot capture the non-physical constraints that guide actions, an extended version of the model must be created to adequately model an education system for planning and formative evaluation. The types of task analysis examined earlier are able to capture typical types of actions in the system, but they neither situate the actions within the context of the full work domain, nor highlight the environmental constraints that necessitate those actions. Rather they typically only model activity at one or a few levels of abstraction without identifying how the actions require parallel physical actions and cognitive activities, and how they support the system goals. Also, normative types of task analysis, including hierarchical task analysis, have more rigid structures focusing on linear sequences of events that may not be descriptive of the variable and fluid behaviors that take place in education. Thus, the models reviewed here have desirable characteristics when examining education, but neither representation is adequate in isolation.

2.4 Requirements for a New Modeling Approach

Rather than creating parallel models based on work domain analysis and one type of task analysis to examine education, this dissertation seeks to combine the desirable aspects of the two into one new, combined model with a corresponding framework for action representation. As this new approach will be based on other methods in cognitive engineering, it will also apply to complex sociotechnical systems in general, but will be most applicable when used to examine learning service systems, notably education, where actions must be captured in the context of the whole work domain and both environmental and cognitive constraints must be identified.

This new approach will draw on work domain analysis for the levels of abstraction and parts-whole decomposition that an expert would use to model the work domain. This provides a representation of the entire work domain, which, due to the interrelated nature of education, is necessary for evaluation. In addition, the new representation can distinguish the different roles of humans beyond what is currently done with work domain analysis. From task analysis, the new framework needs to focus on the actions of people within the system. By combining the strengths of these established methods, the actions can then be situated in the work domain and related to all relevant levels of abstraction. Table 5 summarizes the qualities of this new method in relation to the methods reviewed above. A new general modeling framework that fits this description is described in chapter three and is discussed in terms of an educational system.

Table 5: Comparison of reviewed analysis methods and new, desired method

	Work Domain Analysis	**Control Task Analysis**	**Hierarchical Task Analysis**	**New Method**
Constraints Examined	Environmental	Cognitive	Cognitive	*Environ-mental and Cognitive*
Scope of Analysis	Environment where work takes place at different levels of abstraction	Actions and their sequence	Actions and their sequence	*Actions and the Environm ent*
Examines Actions of Agents	No	Yes	Yes	*Yes*
Represents tasks sequentially	No	Partially – recognizes shortcuts taken in procedures, but focus is on the typical sequence	Yes - typically	*No*
Examines multiple agent roles	Identifies roles, but only in same work environment and without describing interactions between them	No – typically focuses on a single role	No – typically focuses on a single role	*Yes*

CHAPTER 3

WORK ACTION ANALYSIS

3.1 Learning Service Systems

3.1.1 Defining Learning Service Systems

As established in section 2.3, education systems can be viewed as complex, sociotechnical systems for analysis with cognitive engineering methods. However, it has qualities that do not lend it to traditional cognitive engineering methods reviewed in section 2.1.3. These are discussed in section 2.4 and include that both cognitive and environmental constraints play significant roles in shaping behavior, that actions of agents and the environment interact to induce learning, and that multiple agents interact to accomplish the system goals. This class of systems is defined in this thesis as learning service systems, i.e., systems whose primary function is to enable learning by one type of cognitive agent via the teaching of at least one other type of cognitive agent. Learning service systems are defined here for the first time. Learning service systems do not include learning how to produce a tangible product as an end in and of itself, but may include producing tangible products in the service of learning knowledge or cognitive skill. Cognitive skill has been defined by VanLehn as “the ability to solve problems in intellectual tasks, where success is determined more by subjects’ knowledge than by their physical prowess” (VanLehn, 1996, p. 513).

3.1.2 Underlying Viewpoints on Behavior in Learning Service Systems

As discussed in chapter two, cognitive engineering views environmental and cognitive constraints as determinants of human behavior. Work domain analysis focuses on the environmental constraints in a system, as reflected in the structural means-end relationships described by the typical abstraction hierarchy (Vicente, 1999, p. 162). However, models of learning service systems must consider cognitive activity in addition to physical structure. All human work tasks require some cognitive activity, but in learning service systems learning is a defining characteristic. Physical interactions with the environment are undertaken to enable the cognitive activities of learning, so both types of constraints must be considered.

Also, non-physical elements, such as information, play a significant role in learning service systems. For example, in education the diffusion of information is a fundamental part of a course that imposes constraints on all aspects of behavior. Thus, an examination of structural means-end relationships may account for the course textbook, but not for the information flow enabled by the textbook, handouts to the students, and lectures. Since the diffusion of information is integral to cognitive activity, especially in learning service systems, an analysis of such domains must include it along with any other non-physical elements.

Therefore, if learning service domains are to be adequately modeled, they cannot be examined exclusively from a cognitive or ecological perspective. Rather, they must be examined from both to capture all the relevant constraints on behavior relative to the agents' objectives. These constraints can come from physical elements of the environment, from non-physical elements such as information, and from the inherent requirements for cognitive activities.

3.2 Description of Work Action Analysis

3.2.1 Overview

A new type of work analysis is presented here for the first time called work action analysis (WAA). WAA draws on both cognitive and ecological approaches to work analysis and combines their strengths into one analysis method and one corresponding representation. Both cognitive and environmental constraints should be considered in a work analysis: "[b]ecause work demands are usually composed of both cognitive and environmental constraints, there can be little argument that work analysis should include an investigation of both types of constraints. To overlook either would be a mistake…" (Vicente, 1999, p. 48). Though both should be included in a work analysis, there is no single analysis approach that examines and represents both concurrently. Thus, to date "[t]he dilemma is in deciding which type of constraints should be given most importance. Should a work analysis begin with … cognitive constraints or environmental constraints?" (Vicente, 1999, p. 48). Rather than selecting one approach or the other, WAA places the actions of the human, shaped by cognitive constraints, in the context of the actor's objectives and the atomic elements, i.e., information and physical elements that serve as environmental constraints.

Work action analysis is thus defined as a form of work analysis specific to learning service systems that places the simultaneous cognitive activities and physical actions in the context of objectives and constraints. The scope of a WAA includes the system goals, objectives of the agents, objects of a work domain, and the typical set of physical actions and cognitive activities. WAA places the physical actions and cognitive activities in the context of the environment through a means-end hierarchical framework, showing the relations between each. WAA does not attempt to identify every possible physical action or cognitive activity that can be part of a task; rather it identifies the set of those that will typically take place. As opposed to most forms of task analysis (e.g., hierarchical task analysis), it does not specify a sequence of those actions.

Model representations created from a WAA are called work action analysis models. Like other cognitive engineering models, WAA models can be descriptive or formative, depending on their use, i.e., they qualitatively describe a system that is either being designed or is in use, rather than being predictive. The purpose of a WAA model is related to the needs of the person using it. If a system designer creates a WAA model of the conceptual system, the representation will be used in a formative sense and may inspire changes in the designer's mental model and the actual design. When evaluating an existing system, a WAA model can be used in a descriptive sense to show how the system currently functions.

3.2.2 Characteristics of Learning Service Systems Examined by Work Action Analysis

The learning service domains to be studied, such as education, have a set of characteristics that must be included in an analysis of those domains. These include the relations between physical actions and cognitive activities, relations between each of these and the environment, and the roles of cognitive agents within the system.

3.2.2.1 Physical Actions and Cognitive Activities

As described at the beginning of this chapter, cognitive activity plays a prominent role in the learning service domains for which WAA is intended, such as education. Physical action is distinct from cognitive activity, yet the two are related and interact. It must be recognized that physical actions and cognitive activities typically occur simultaneously at different, adjacent levels of abstraction within the domain. Physical actions involve direct manipulation of and interaction with physical objects in the environment, and so are close to the physical objects in a hierarchy of abstraction.

Cognitive activities take place in the arena of the brain/mind, and often stem directly from the desire to achieve the higher level goals of the task. For example, in the process control task of short order cooking Kirlik observed workers physically arrange the task environment to align with their cognitive activities of monitoring the orders on the grill (Kirlik, 1998). Three different strategies for this task were observed, each with different physical actions that necessitated their own associated cognitive activities. Here, the cognitive monitoring task is directing the physical action of cooking the orders, and the physical actions are shaping the environment that the cognitive activity is monitoring. In perhaps the most efficient strategy, the workers place the meat for an order at varying left-right positions on the grill depending on the type of order and then move them to the right at the same rate, thus knowing they are done when they reach the right side of the grill. Likewise, recent work in cognitive science in the area of situated cognition has brought broader recognition of the importance of such interactions between the human cognitive activities and the environment (e.g., Clark, 1998; Hutchins, 1995).

In learning service systems, the interplay between cognitive activities and physical actions is connected to the purpose of these systems, namely learning. Learning necessarily and immediately involves cognitive activities, and physical actions are performed as part of engaging in those cognitive activities. For example, a student may perform the physical actions involved in reading a textbook (i.e., holding the book, moving eyes over the page). The immediate purpose of performing these physical actions is to acquire the knowledge in the book, a cognitive activity, which supports the overall objective of learning. This relation between cognitive activities and physical actions must be considered when modeling a learning service system.

3.2.2.2 Levels of Abstraction and Means-end Relations

Modeled at adjacent levels of abstraction, physical actions and cognitive activities have a specific type of relationship. While they can be distinguished, it is not possible to separate the cognitive and the physical, nor can one be said to drive the other as both must take place to support each other. Instead, means-end relations relate elements between levels of abstraction by identifying two system elements where one is the means for accomplishing the other. This type of relation exists between cognitive activities and physical actions in learning service systems, where physical actions are ultimately the means performed to accomplish cognitive activities. As in the example above of reading a book, a student is engaged in the physical action of manipulating the book to the cognitive end of comprehending its content.

There are other elements of the system, such as objects in the environment and system goals, that also play key roles in learning service systems. In cognitive engineering, physical actions are often considered separately from elements of the environment. In Pejtersen and Rasmussen (1997) and Lintern and Naikar (1998), for example, where work domain analysis and decision ladders are suggested to represent the work domain and actions respectively, the two analysis methods capture actions and the environment of the task separately. Yet, the ecological approach's view that the environment has a major role in determining behavior can not be separated from the actor. The ant in Simon's illustration (Simon, 1981) takes action in relation to the task goals (e.g., transport food to the colony) and the physical objects (e.g., contours and obstacles of the beach), which are both important to work.

Not only do physical objects in learning service systems shape behavior, other non-physical aspects of service systems serve as fundamental, atomic elements to support the physical actions and cognitive activities. As noted earlier, for example, information plays a significant role in education and is embodied in physical objects such as textbooks and electronic files, such as PowerPoint presentations. Yet, the information itself is intangible and is as much a means to accomplishing physical actions as are the tangible objects, regardless of how it is physically communicated or stored. In education a grade on an assignment can be communicated in writing, verbally, or electronically, but the information of the grade is the important component of learning, not the conduit used to transmit it. The lowest level of abstraction in learning service systems must include both the tangible and intangible elements that are the means to accomplishing the physical actions and cognitive activities.

The term "structural" in structural means-end relations emphasizes that, in work domain analysis, these relationships are between (physical) structures in the environment. The levels of abstraction in WAA include physical actions and cognitive activities, requiring a different type of means-end relation between these elements. The means-end relation used in WAA is defined as agent-environment means-end relations. The term “agent-environment” signifies that these are means-end relations between environmental elements and elements related to the agent’s physical actions and cognitive activities, emphasizing the interaction between these elements in real-world tasks. Agent-environment means-end relations exist between each level of abstraction in WAA: from the environmental atomic elements to physical actions, from physical action to cognitive activities, and from cognitive activities to the agent’s objectives.

3.2.2.3 Roles of Cognitive Agents

Another aspect of learning service domains is the interaction of multiple cognitive agents, typically humans, in different roles. The definition of cognitive agent used here is based on Hayes': "an *agent* is an entity (either computer, or human) that is capable of carrying out goals, and is part of a larger *community of agents* that have mutual influence on each other" (Hayes, 1999, p. 127, emphasis hers). The first part of this definition states that agents perform actions to carry out goals. To do so implies that agents must have some ability to perform actions and that those actions are directed to meet goals. Hayes' definition is extended here to note that there must be some cognitive (or computational) activity internal to the cognitive agent that serves as a means-end link between actions made on the environment and the agent's goals. The second part of Hayes definition states that it is part of an agent's nature to interact with other agents. While it may be possible to conceive of and define a learning service system where there is only one cognitive agent, the multi-agent case will be considered here for two reasons. First, modeling the single-agent case is a subset of the multi-agent case. Second, cognitive engineering methods need to be able to account for multiple cognitive agents (e.g., Woods & Roth, 1988).

Hayes also defines the term roles with respect to agents: "[w]hen agents have specialized functions they are said to have individual *roles*, such as pilot, navigator, or mechanic" (Hayes, 1999, p. 127, emphasis hers). Each role is working in the same system and may perform similar work on the same system elements. However, different roles may also interact with different elements of that system and perform different tasks. The various roles may have some objectives in common related to the overall success of the system, but they also have objectives that are directly related to their own role and are not shared with others. In addition, one role may create the environment of other roles, such as in the case of instructors creating part of the environment for students in a course by creating the assignments and grading formula. The modeler must determine whether or not the cognitive agents have sufficiently specialized functions in the context of the purpose and specific use of the analysis. For example, in one model it may be necessary to distinguish between the roles of pilot, copilot, and navigator, while in another it may be sufficient to distinguish the role of the cockpit crew from the role of the cabin crew.

As noted in chapter two, work domain analysis has attempted to represent different human roles by showing each as having a region of responsibility in the work domain (see Figure 2). While this method represents each role within the work domain and the areas of overlap between their respective responsibilities, it does not represent how one role interacts with the other. The areas where the roles overlap do not specify the relation between the roles. Nor can this method represent one role creating the environment for another. As there can be a large number of system elements that are exclusively related to a single role, it is necessary to distinguish between roles in WAA and the representations associated with each. The following section describes how this is represented in WAA.

3.2.3 Purpose of Work Action Analysis

The purpose of WAA is to be a method for the design and evaluation of learning service systems. In this, it has similarities to ecological interface design, which was reviewed in section 2.1.4.1. In EID, a model is made of the operational system and measures are integrated with that model to create an ecological interface. This interface is then used by an operator to control the system. The role of the operator is that of an evaluator performing a formative evaluation. The purpose of the model is to capture the operation of the system so the operator/evaluator can control it.

Here, it is useful to distinguish between the operational aspects of a system, and the evaluation and control aspects. The operational aspects of a system are the elements that are working to meet the system goals. For example, in a process control system, the operational aspects are essentially the process that is being controlled, excluding the controller and control activities. The evaluation aspects of a system are those that are examining the system to determine if it is meeting its goals. These may also include control of the system where the evaluation is used to change system parameters to more effectively meet the system goals.

It is possible to model this type of system with at least two different scopes. First, both the operational and evaluation and control aspects can be included in a single model that identifies the parts of the system that are in operation to meet the system goals and the parts of the system that are used to evaluate and control that system. Second, just the part of the system that is in operation to meet the system goals can be modeled, excluding the evaluation activities. While the first type of model and scope is useful for certain types of analysis, it is not useful to support the task of evaluating and controlling the system. Instead, this type of model is best applied to predicting the system behavior in response to its control and evaluation mechanisms. The second type of model and scope does support the operator's task of controlling/evaluating the system. The operator uses the model of the operational system along with measures of it to determine how to control it. This second type of model is therefore used by EID and similarly by evaluation of learning service systems using WAA.

3.3 Framework of Work Action Analysis

WAA was developed for the purpose of evaluating a range of learning service systems. The following sections describe the conceptual WAA model framework, with specific examples of its application to a particular type of learning service system, namely and undergraduate engineering course.

3.3.1 Dimensions

The WAA framework consists of three dimensions: (1) parts-whole, (2) means-end, and (3) roles of cognitive agents. The first two are hierarchical in nature, while the last is categorical. While these dimensions will generally apply to a WAA of any system, the meaning of each level of each dimension and the number of levels may be further tailored to specific applications. These dimensions are described in the following sub-sections. A schematic diagram of the WAA framework is shown in Figure 12.

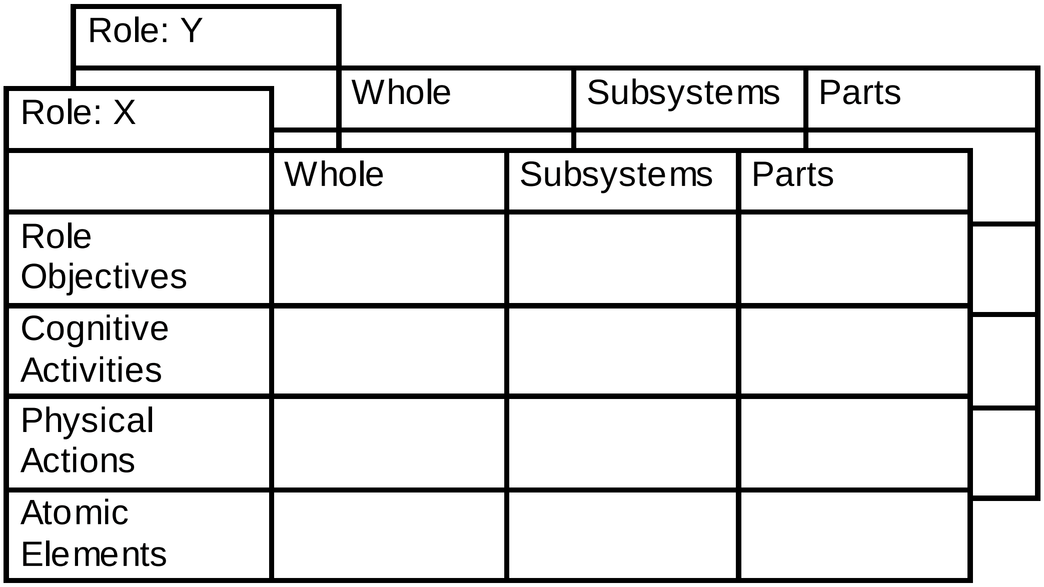


Figure 12: Schematic of the Work Action Analysis Framework

3.3.1.1 Means-end Decomposition

As described previously, means-end decomposition separates the system into levels of abstraction. As with work domain analysis, the levels used for a specific task should be chosen specifically for that task, so more or less levels may be required. Four levels are presented here for WAA from lowest to highest abstraction: atomic elements, physical actions, cognitive activities, and role objectives.

The lowest level of abstraction is called the atomic elements, which is analogous to the physical form level in work domain analysis' structural means-end abstraction hierarchy (Rasmussen, 1985). Here in WAA, this level is broadened to include other types of resources, such as electronic files and items of information, that enable and constrain action but are not necessarily physical. This is within the original intent for this level in the abstraction hierarchy as it identifies the resources required for the actions to be performed (Rasmussen, 1985). Items at this level contribute to the system when a cognitive agent creates or interacts with it, but are not themselves actions.

In light of the previous discussion regarding the distinction between physical actions and cognitive activities, a distinction is made in the hierarchy between the two by placing them on separate levels. The level of abstraction above atomic elements identifies physical actions, which are defined as the physical behavior performed on and with the atomic elements. This may include various manipulations of physical objects such as typing on a keyboard, giving a presentation to an audience, and playing an instrument. Physical actions include creating or interacting with atomic elements using physical movement and thus are linked to atomic elements by agent-environment means-end relations. Here, the agent-environment links emphasized are the physical manipulations of the human performed on the atomic elements (both physical and non-physical) in the environment. The atomic elements are indicated as the necessary means to accomplish the physical actions, as the physical actions would have nothing to create or manipulate without them. For example, an instructor creates information in the form of feedback when grading an assignment using pen and paper.

Another property of physical actions is that they are physically observable and thus can be observed with process measures. The physical actions take place in the environment and in relation to the atomic elements. Interactions with these atomic elements can be recorded in a variety of ways, but their meaning is dependent on the context within all levels of abstraction. For example, the amount of time taken to complete a physical action can be collected for any given action, but this process measure may not be meaningful in situations where goals such as safety and accuracy override the need for speed.

Cognitive activities are the next level of abstraction. These will be described for human agents, but apply equally to the computational activities of computer agents as well. Cognitive activities are the internal, unobservable activities of the mind. Cognitive activities cannot be physically measured in the brain in a typical work environment (at this time), but they can be indirectly measured or inferred through measures of the related physical actions. Due to their connections, it is inferred that when physical actions are completed successfully, the expected cognitive activities have been enabled and, if the objectives were also met, have taken place.

Agent-environment means-end relations link physical actions and cognitive activities. Here, the means-end relations indicate that the cognitive activities are the reason the physical actions are performed and the physical actions are the enablers of the cognitive activity. These are agent-environment means-end relations since they link the physical actions that interact with the environment with the cognitive activity that is fully internal to the cognitive agent. These relations also indicate that the physical actions and cognitive activities are taking place concurrently. For example, a student writing a paper is concurrently performing the physical action of writing and the cognitive activity of constructing an argument. The agent-environment means-end relations also show how a physical, environmental constraint, if present, can propagate to constrain cognitive activity, and how cognitive constraints will require physical actions.

Role objectives is the next highest level of abstraction considered here and consists of the overall objectives for each role. Ultimately, within each role, all system elements at other levels should be means of achieving the objectives for the agents in that role and so should be connected to them through the means-end relations between levels.

The fact that cognitive activities are immediately below the role objectives in the levels of abstraction emphasizes the importance of the cognitive activities in the learning service domains for which WAA is intended.

Overall system goals are represented at the level of role objectives. System goals may be matched with roles in various configurations, possibly with some goals shared by different roles, and some roles not explicitly meeting system goals. Roles can also have their own objectives in addition to the overall system goals. The relation between system goals and role objectives will be discussed further below.

Cognitive activities and role objectives are related by agent-environment means-end relations, linking the agent's cognitive activity to their goals. These are means-end relations as the objectives are accomplished through the cognitive activities (which in turn are supported by the physical actions and atomic elements) and the objectives are the reason for performing the cognitive activities. These relations reflect the key place occupied by cognitive activities in learning service systems as the immediate means to accomplish the objectives.

3.3.1.2 Parts-Whole Decomposition

The parts-whole dimension of system decomposition is used to break down larger system elements into smaller ones, such as breaking a physical system down into meaningful subsystems. Granularity is a significant issue as it is necessary to examine the system both as a whole and at an appropriate level of detail for the purpose of the analysis. The purpose of this dimension is to maintain the overall context of the system as well as capture the smallest relevant details. The number and content of the levels of the parts-whole dimension must be set for individual domains based on natural divisions in that domain. An example from work domain analysis is a manufacturing process, which can be physically divided from the plant as a whole into individual product lines, specific process areas, and individual work stations. The lowest level of this dimension includes the elements at the smallest meaningful level of detail for the analysis. These are then grouped together in the natural, meaningful groups and divisions in the environment, until the largest meaningful "whole" is collected at the highest level.

As learning service systems studied by WAA must include an examination of the environment along with the cognitive aspects of the roles, the parts-whole dimension is not a decomposition of only the physical environment. By including physical actions and cognitive activities in the means-end decomposition, the system elements do not simply stand in a spatial relation to each other as they do not solely include physical elements of the system.

Rather, WAA divides the system along natural groupings from larger to smaller levels of granularity. The question "is the element at the lower level a component of the element at the higher level" identifies a WAA parts-whole relationship. Each level of the parts-whole dimension indicates a set of elements that together form one level of granularity of the system. Sets of actions and activities can, and often do, have a temporal relation in that they must be performed in sequence. For example, in education it is typically the case that one set of material must be learned via one set of simultaneous physical actions and cognitive activities before another, as the former provides the foundation for the latter. In such cases, it is necessary to recognize these temporal relations in the analysis. Thus, there may be multiple sets of elements at each level of granularity which are performed in a specified sequence.

3.3.1.3 Cognitive Agent Roles Decomposition

The cognitive agent roles dimension is not hierarchical like the other two; rather, it is a categorical dimension listing the different roles. While there will be some overlap in the elements of the system that fall into each role, this separation between the roles is necessary to identify what atomic elements, physical actions, cognitive activities, and objectives are associated with each role. In WAA, each role will have its own two dimensional means-end and parts-whole framework.

While the roles are distinct, they are not isolated from each other. As noted earlier, one role can impact the other. Roles interact with each other at the atomic elements level, where information and physical objects exist and are shared by the roles. Not all atomic elements need be shared by other roles, but the ones that are shared are the means for one role to affect another. Thus, two roles are linked by *correspondence* relations between their atomic elements. Two atomic elements are said to have a correspondence relation when they are essentially the same and they are atomic elements in at least two different roles. For example, if a textbook is used in a course, it would be an atomic element for both the instructor and student and a correspondence relation would exist between the roles at the point of the textbook. This example also shows how one role shapes the behavior of another: the students have the textbook as an atomic element because the instructor designated it for the course.

These correspondence relations can be used to trace the impact of one role on another. One role can influence another through creating or specifying atomic elements for other roles to interact with via physical actions. The creation, specification, and interaction with the atomic elements by both roles is captured in each role's individual representation, and the relations between these activities and actions are represented by the correspondence relations.

Correspondence relations also exist between role objectives and system goals. A system can have overall goals, such as the course objectives as stated in the syllabus. Multiple roles may be attempting to achieve the system goals, and not all roles need be attempting to achieve all (or any) of the goals. When an overall system goal is also a role objective, the role objective has a correspondence relation with the system goal. When this is true, the system elements for that role should be aligned so that the objective will be met, and the atomic elements of that role should be designed to influence other roles that must assist in meeting that objective.

For example, in the case of the roles of instructor and student, the instructor creates and specifies atomic elements, such as an assignment, for the student, which in part shape the student's behavior. The student is also guided by role objectives, such as achieving a high grade, by which the student makes decisions about the amount of effort to spend on an assignment. The instructor must design an assignment in a way that encourages students to be engaged in the actions and activities required while driven by the students' own objectives. The instructor must also design an assignment to meet the overall system goals, which correspond with some of his or her role objectives for the course.

This method of representing roles of cognitive agents is in contrast to how they have been previously represented in work domain analysis, as noted in chapter two. Previous representations of roles in work domain analysis do not include relations between the roles showing how they influence each other, nor relations between role objectives and system goals.

3.4 Method for Creating a Work Action Analysis Model

Now that the general framework for a WAA model has been established, the application of that framework to a system can be described. A general method for tailoring the framework to a domain and then populating a model is presented here. This method is specific to WAA, but is based on methods for creating work domain analysis models as given by Rasmussen et al. (1994) and Vicente (1999). As in work domain analysis, these high-level methods should be seen as guidelines as there may be specific needs for particular types of domains and tasks; detailed processes more specific to particular domains and tasks can be formed within these guidelines. Also, these guidelines should not be followed in a strictly sequential manner without iteration. Instead, the modeler should use the modeling process to gain insight to the system, which in turn leads to refinements to the framework and model established in previous steps. Indeed, each step is not a straightforward instruction and may be iterated within itself.

3.4.1 Method

1. *Determine the scope and purpose of the analysis.* Both the scope of the system to be examined and the purpose of the analysis must be specified. These will serve as boundaries and guides to creation of the model. This is an essential step to the method as it sets the context for the analysis. Based on the scope and purpose, the modeler will determine what system aspects and level of detail are meaningful for this analysis.
2. *Determine the system goals.* The goals of the system, which is bounded by the scope and purpose in the previous step, must be identified. The system

goals should be ultimately achieved by all roles acting collectively.

3. *Identify all the roles of cognitive agents that are integral to the system.* These should be identified relative to the scope and purpose of the analysis. This step should be relatively simple when the roles are clearly delineated (e.g., student and instructor) relative to the purpose and scope of the analysis.
4. *Identify the levels of the parts-whole and means-end dimensions.* Working from the whole system established by the scope and the purpose of the analysis, relevant components should be identified. As noted earlier, there may be an established system of division into components that can be used to design the parts-whole dimension. In some cases it may be necessary to deviate from this division when it does not reflect actual work practices or support the scope and purpose of the analysis, either by leaving out levels of organization, or brainstorming and attempting several different divisions. It is also necessary to consider temporal relations to determine what parts should be seen as temporally related and may require separate representations at the same parts-whole level of granularity. In parallel with the parts-whole dimension, the definition of each level of abstraction along the means-end dimension should be determined. The general categories of the four levels of the means-end dimension identified here are atomic elements, physical actions, cognitive activities, and role objectives. Some domains may require slight deviation from these general categories and/or different numbers of levels to properly analyze a particular system for a particular purpose. The schematic framework presented in Figure 12 with defined categories in each

dimension is the final product of this stage.

5. *For each role, fill in the items at the lowest and highest levels on the means-end and parts-whole dimensions, so that the top left and bottom right corners of the framework are populated (Figure 12).* Identifying these items in the highest and lowest levels will keep the model bound by the designated scope and purpose, allowing the middle levels to be specified in relation to them through the parts-whole and means-end relations. Also, the items in these corners of the framework are typically easiest to identify.
6. *For each role, fill in the items in all other levels, identifying relations between levels as appropriate.* Once the elements from step five are specified, elements of levels in between can be identified by their level of abstraction, level of granularity on the part-whole dimension, and relation to other elements in the model. At this point, the "how" and "why" questions must be used to determine if items at different levels of abstraction are related by means-end relations, which are the only relations that should exist between levels of abstraction. If two items in adjacent levels of abstraction are related, the one at the lower level will identify "how" the other is accomplished, and the one at the higher level will identify "why" the other is performed. Parts-whole relations must also be identified, which specify the items that are a part of a larger whole (e.g., components are parts of subsystems and subsystems are parts of the whole system). These questions will also suggest new system elements by making the analyst consider all the system elements that may be means to an end and ends of a means, or parts of the whole. It will be

necessary to periodically double-check the elements and their relations using these questions to ensure all items are in their proper locations in the model. In parallel, the analyst must identify temporal relations between elements that may require separate representation, and relations between roles where one is affecting the other.

7. *Identify correspondence relations between roles, and between role objectives and system goals.* Correspondence relations can exist between atomic elements in different roles and between role objectives and system goals. Identifying these relations is necessary to determine if the roles are aligned with system goals and if all roles are aligned with each other. In a well aligned system:
   - all system goals have a correspondence relation with at least one role objective,
   - all roles with at least one system goal corresponding to a role objective have correspondence relations via atomic elements with other roles needed to meet that goal, and
   - all roles are related to the overall system goals either through correspondence relations of role objectives and system goals or via correspondence relations of atomic elements to roles that are explicitly meeting system goals in their role objectives.

3.4.2 Framework Templates

In addition to using the method in the previous section to create a WAA model, a modeler capitalize upon templates of WAA models that closely match the system under study. Once one system in a domain has been modeled with the WAA framework, these can be used to build template frameworks and specific development methods for other such systems within the domain. While specific tasks and situations may differ, there will be general patterns of work for these systems. For example, many undergraduate courses follow a similar pattern: students attend lecture, work through weekly assignments, take tests on the material, and receive graded feedback. The tasks performed in these courses are very similar to each other, so that a set of templates could be made for major aspects of the course such as a typical homework assignment and the material, lectures, and grading that are associated with it. Each of these courses, while taught by different instructors with different content, could benefit from a similar pool of templates. The pool of templates need not be large enough to include every possible situation, but should cover the typical case of tasks that occur frequently. Even if a situation is not covered by the templates, the templates can suggest ways to model it. As more systems are modeled, more templates can be generated to support modeling other systems.

Also, when a new pedagogy is identified as desirable for a given learning service system, templates based on the pedagogical methods can be created showing how to apply that method. This may involve the introduction of new educational technology, adoption of a new method of classroom instruction, or inclusion of any other change in the system. Again, these need not identify every possible way to use the new method for learning, but will provide the modeler with a baseline for tailoring a model to a specific situation.

The templates do not eliminate the iterative method of creating a WAA model, but enhance it by providing more support to the modeler. Unless the template is for the exact same system being modeled, it cannot simply be copied to use for a new system and will require modification. To take advantage of templates when modeling, the modeler would begin the WAA method as outlined above. When the modeler reaches step three, which is to identify the roles of cognitive agents, the modeler should also being looking through available templates for models where the first three steps are similar. Over the course of steps four through seven, the modeler can continue to examine the templates for systems that are similar and use as much as is needed from the templates. If the system being modeled is very similar to one in the templates, the modeler could simply copy the set of templates and make small adjustments as necessary. If the system does not match a set of templates, some aspects of the templates can still guide the modeler in where to place certain types of elements in the model.

3.5 Work Action Analysis for Higher Education

Having presented the general framework of a WAA model, this section demonstrates how this framework and method can be tailored to a university level course to illustrate its use and to establish a method and template more specific to education.

3.5.1 Applying the WAA Method to a Course in Higher Education

3.5.1.1 Determine the scope and purpose of the analysis

In this example, the scope of the analysis is limited to a single undergraduate course and the purpose of the analysis is the planning and formative evaluation of that course. This guides the modeler to focus on evaluating the system of the course as a whole with its constituent parts. In other cases, a broader scope (e.g., curriculum) may be desired, in which courses are included as constituent parts.

3.5.1.2 Determine the system goals

The system goals of an undergraduate course can be identified as the course objectives written in such a manner that they are useful for evaluation. Course objectives are often written poorly and without a view toward being measurable for evaluation (St. Clair & Baker, 2000). Even if an objective is stated in a measurable form, it may not identify the correct level of learning that is desired in the system. If the objectives are not properly stated for the system, it will be difficult, if not impossible, to determine if any cognitive activities support the system goals. Conversely, through thinking through the cognitive activities expected of the students, the iterative method of performing a WAA can help clarify and detail course objectives.

3.5.1.3 Identify all the roles of cognitive agents that are integral to the system

The roles of the instructor and students in the education system are different in terms of their actions and goals at the scope of a single course and for the purpose of planning and formative evaluation. Typically the instructor creates or provides the atomic elements and specifies the physical actions corresponding to cognitive activities desired of the students. In pursuit of their own objective, the students interact with, and often react to, the atomic elements from the instructor, participate in the physical actions, and create their own atomic elements such as study notes. There is deliberate influence at the level of atomic elements, particularly from the instructor to the students, but the roles are significantly different and may be represented as different work environments that strongly impact each other without being experienced in the same way by students and instructors. It may be necessary in some cases to add other categories in this dimension, such as for teaching assistants who have a distinct role in assignments, office hours, and lab exercises.

3.5.1.4 Identify the levels of the parts-whole and means-end dimensions

In order to feasibly study an educational system such as a course, it is necessary to decompose it from a whole into relevant parts. This is not just so the parts can be examined in isolation, but also to identify the contribution of individual parts to the whole of the system. The following is one scheme to decompose a course into parts that accords with the typical structure of undergraduate engineering courses. This is not the only structure that can be used, nor is it the most appropriate for every course.

The most detailed form of information in education considered in this framework is the individual topic of course content. A topic is a single cohesive concept that students must learn as part of a course (Pritchett et al., 2002). Topics are associated with specific instructional material, which may include a section or chapter of a textbook, a lecture, and/or paper or electronic notes. There is no restriction on the size of topics in terms of breadth or depth, but it is suggested that a topic may range from small (3-4 topics per class lecture) to large (1-2 class lectures per topic). Students interact with topics via physical actions. Each topic has a set of actions associated with it that are designated, either explicitly or implicitly, by the instructor to acquire the knowledge and/or skill of the topic. These actions may include reading and memorizing the topic material, or applying the topic to a specific application to gain design experience. Thus, the topic level of this dimension includes the individual topics in a course and any actions, activities, and objectives that are immediately related to them.

The next level of the parts-whole dimension consists of assignments. Many undergraduate engineering courses are structured so that an assignment, such as a homework or quiz, covers one or more topics. Thus, a group of (typically related) topics is covered by a single assignment. When the topics covered by an assignment are not all closely related, such as on a comprehensive exam, the assignments tend to have multiple questions where each one relates to a set of one or a few cohesive topics, and can be treated as separate assessments. Parts of the system that may be represented at the level of assignments include atomic elements (e.g., the assessment itself, student submissions for the assessment, and feedback to students on their performance), all physical actions and cognitive activities relating to the assignment, and any immediate objectives of the roles for the assignment stated more specifically than their objectives for the entire course.

Grouping content based on assignments corresponds to normal teaching activities. This structure based on assignments likely comes as much from pragmatic reasons as pedagogy. The instructor schedules topics partially based on when they must be covered to be included in regularly spaced assignments such as homework and tests, and partially based on highlighting a cohesive group of topics. Also, if there is a term-long project the instructor must schedule the project and topics so students can learn the material needed to do the project work. In this case, there will be temporal relations between assignments according to the order in which they are assigned. Students also schedule their work (i.e., physical actions and cognitive activities) for the course in relation to the assignments.

The next level in education is the whole, the course. In the context of this example, a course is a set of assignments made on a set of topics with a consistent instructor (or instructors) that together form a final, comprehensive grade. In undergraduate engineering education, a course typically lasts one academic term, but conceptually a course may be longer or shorter.

In some analyses it may be beneficial to add another parts-whole level for the curriculum. If the scope of the analysis is the entire curriculum, then this level must be added to examine the relations between the individual courses and the curriculum elements, especially the curriculum goals. Also, if the purpose of the analysis is to examine how a course supports the curriculum, then adding this level is necessary.

As for the means-end decomposition, the four levels of the general WAA model framework can be applied specifically to a university course. The lowest level of abstraction, atomic elements, contains physical objects and information such as lecture notes, handouts, homework assignments, and grades. For example, simulation software and an electronic file containing a simulation model are each atomic elements. They are assigned by the instructor and used by both instructor and students during the course, and their use involves action (e.g., running a simulation). Other items such as e-mail messages and feedback from instructors to students on an assignment (in whatever form delivered) should also be classified at this lowest level of abstraction.

Physical actions are the actions performed on atomic elements. These can include creating atomic elements, such as an instructor creating a handout or lecture, and interacting with atomic elements, such as students studying a textbook or working homework problems. Again, these are actions in the course that can be directly observed.

Physical actions do not directly meet the educational goals of a course, rather they are intended to make students engage in cognitive activities; i.e., cognitive activities are the purpose of the physical actions and the means to accomplish the agents' goals (see Table 4). Several physical actions work together, concurrently or sequentially, to produce one cognitive activity; for example, note taking during lecture and subsequent rehearsal of these notes can together produce memorization. The cognitive activities desired in students should determine the physical actions to prescribe to ensure the desired learning outcomes.

The instructor's objectives in education typically include, but are not limited to, the course objectives for student learning stated in the syllabus. Students' objectives may include learning and achieving a high grade in the class, which then motivates their cognitive activities and physical actions. If the course is well-aligned, student activities and actions will enable both the students' objectives to be met as well as the instructor's objectives for their learning.

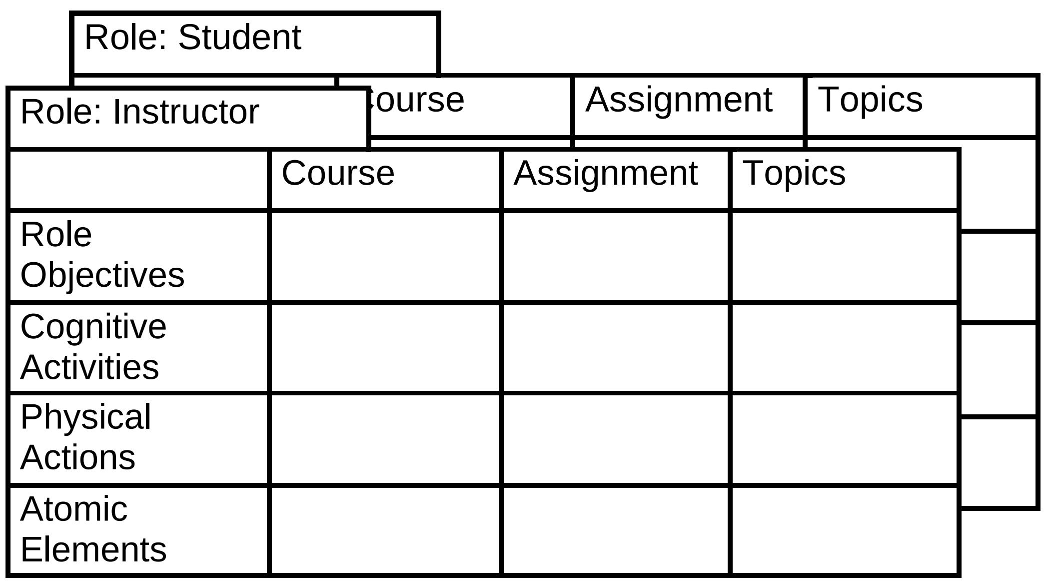


Figure 13: WAA Framework for a Stereotypical Undergraduate Course

Figure 13 shows a WAA framework that is set up according to the guidelines above for a stereotypical undergraduate course. The structure of these levels of abstraction is not intended to favor any one educational approach over the other, but to be general to many educational domains and to accommodate any approach that is selected as the most appropriate for the desired learning outcomes. There are a large number of educational approaches that prescribe a set of physical actions and the cognitive activities associated with them. For example, one cognitive psychology approach to learning suggests students must learn production rules through extensive study and practice (Anderson et al., 1995). Another approach, called constructionism, suggests students must construct their own cognitive meaning by constructing physical artifacts (Papert, 1991). Both approaches can be represented within these levels of abstraction and granularity.

As an example of the means-end relations, Figure 14 through Figure 17 show possible scenarios that may occur in a course. These scenarios represent some of Bloom's categories of educational objectives to show how each would be represented for the role of the student in the WAA framework.

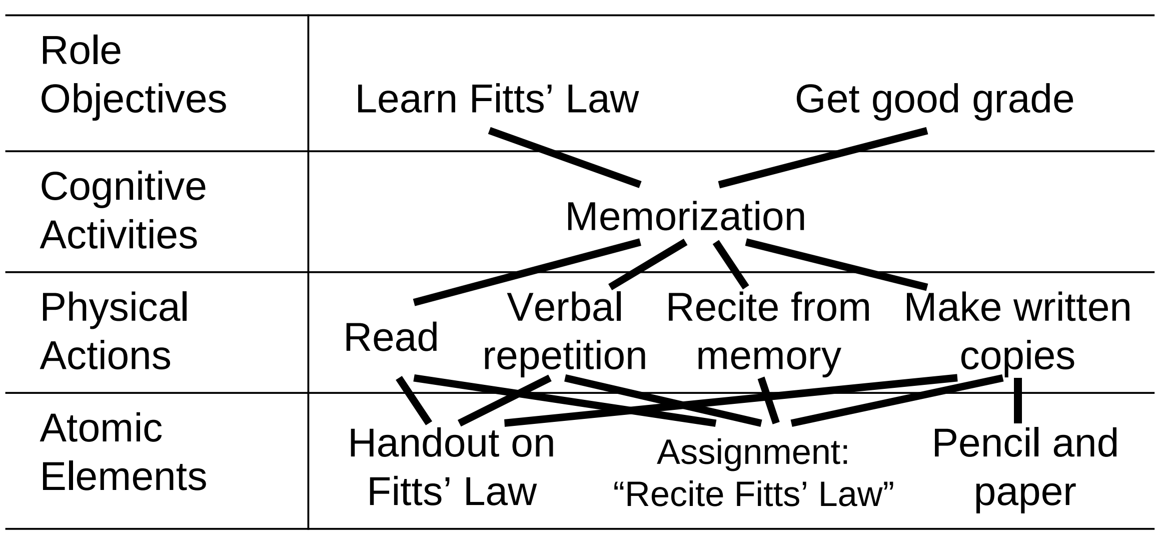


Figure 14: Fitts' Law Scenario for the Student at Bloom's Knowledge Level

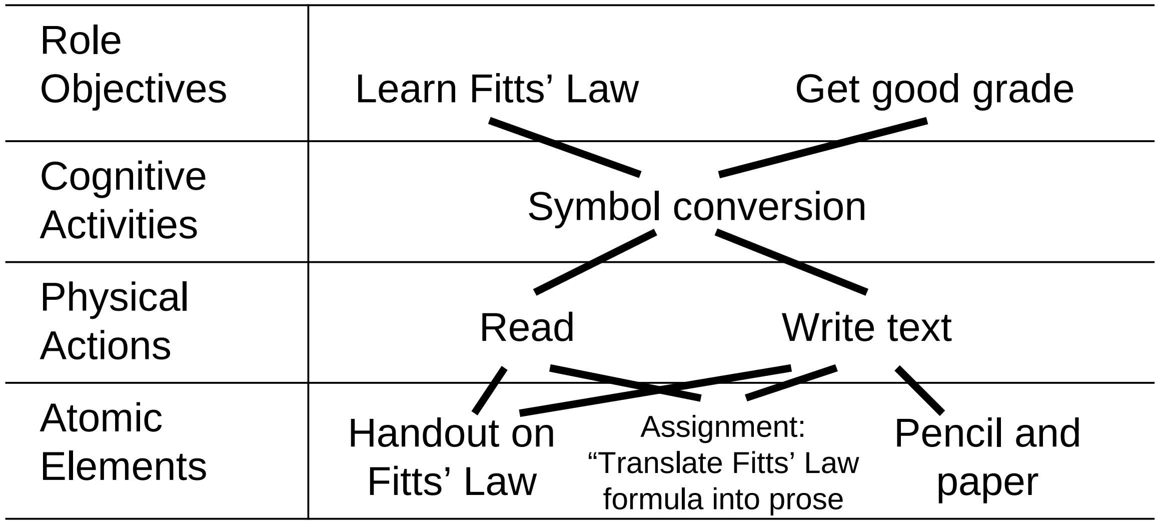


Figure 15: Fitts' Law Scenario for the Student at Bloom's Comprehension Level

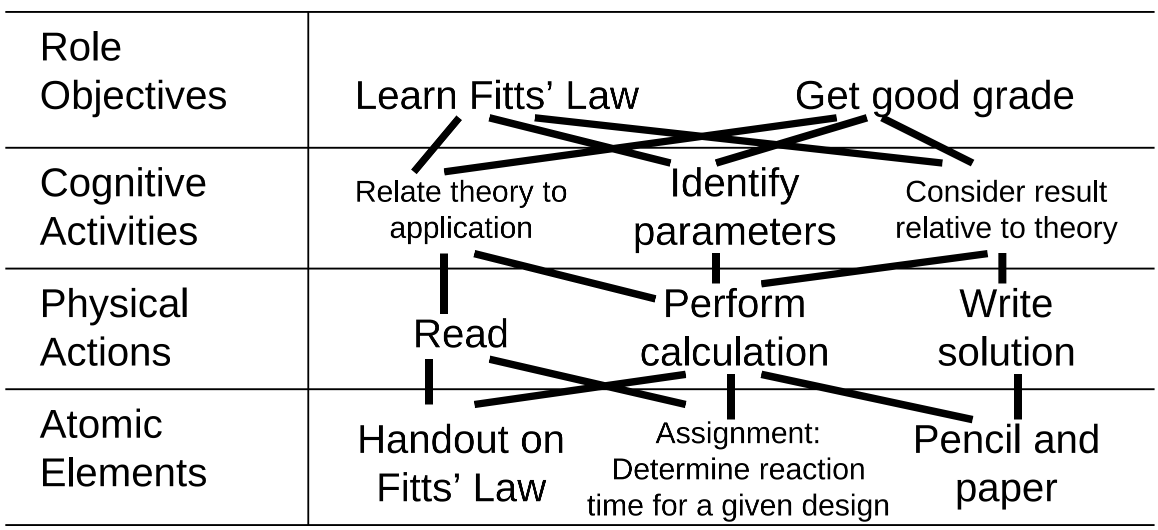


Figure 16: Fitts' Law Scenario for the Student at Bloom's Application Level

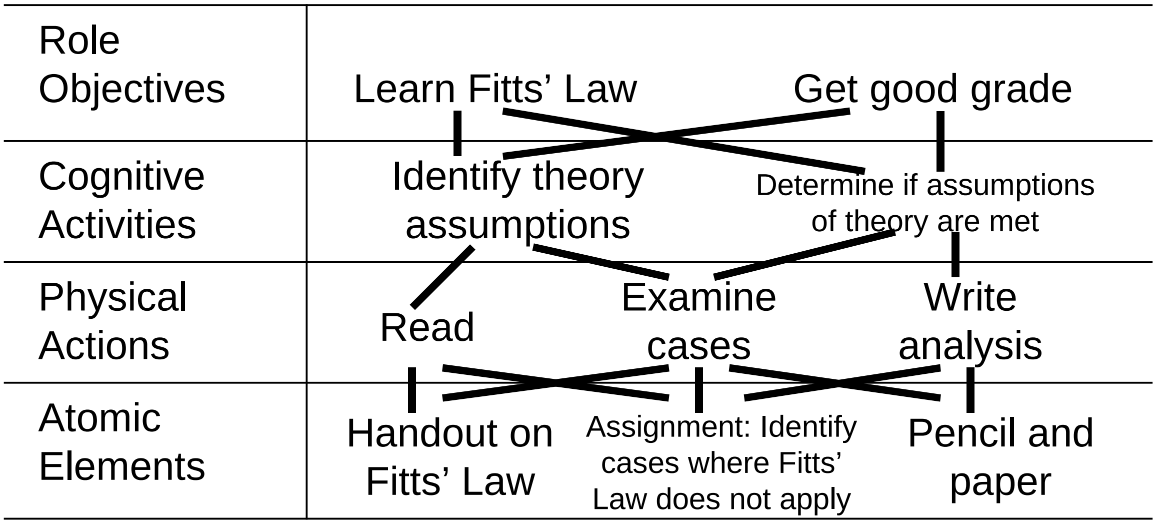


Figure 17: Fitts' Law Scenario for the Student at Bloom's Analysis Level

3.5.1.5 Populate the top left and bottom right corners of the framework

To bound the activity of populating the framework, step five of the method is to fill in the items at the lowest and highest levels on the means-end and parts-whole dimensions. The elements at the highest level of the means-end and parts-whole dimensions will be the objectives of the agents for the course as a whole. At the opposite corner, the lowest level on the means-end and parts-whole dimensions contains the course topics (i.e., the individual items of course content), commonly represented as chapters or sections of a textbook, class handouts, or lecture notes.

3.5.1.6 Populate the rest of the framework

Step six is to populate the rest of the framework with the appropriate elements and their relations. This, along with the rest of this method, is an iterative method, requiring backtracking and double-checking through the various types of relations.

Much of the information needed to populate the framework for a course is already available from typical course preparation activities although it may not all be at a sufficient level of detail. When preparing a course, the instructor will typically set objectives for the course, determine the course content to be covered and what order it will be presented, and specify the general nature of each assignment, when they will be administered, and what content they will cover. Also, some pedagogies explicitly state the type of cognitive activities that they are designed to induce. For example, the constructionist pedagogy is designed so students engage in creating mental constructions of knowledge (Papert, 1991).

In K-12 education, creating lesson plans is part of normal practice, and these lesson plans are defined as documenting many of the elements that should be included in the WAA model. The need to specify objectives and the means to achieve them is particularly emphasized in definitions, e.g., “A written scheme prepared by the teacher that includes the instructional objectives and methods for a particular functional unit or period of instruction” (1988, p. 271). Other definitions go into more detail on the system elements that support the objectives, e.g.,

> “A plan for helping students learn a particular set of skills, knowledge, or habits of mind. Often includes student activities as well as teaching ideas, instructional materials, and other resources. Is shorter (in duration) than, and often part of, a unit of instruction. Goals and outcomes are focused.” (Education Reform Networks, 2004).

In other educational systems, although there are several sources of information for populating the framework, the instructor is not always asked to compile this information into one representation for evaluation. Also, the instructor is not always required to consider explicitly the alignment of course goals with cognitive activities and physical actions. However, considering these aspects of the course in a systemic fashion is necessary for effective evaluation.

3.5.1.7 Identify correspondence relations

In this step, the correspondence relations between role objectives and system goals and between atomic elements in different roles are identified. If the system is aligned, at least one role's objectives correspond to system goals. For alignment in a typical course, the instructor's objectives should include the system goals (i.e., course objectives). It is assumed that the student does not explicitly attempt to achieve the system goals, but is influenced by the instructor so that they are met. The two roles of instructor and student are related by correspondence relations between atomic elements such as the course textbook, assignments, and handouts shared by both roles. Not every atomic element in a role corresponds to an element in another role, such as in the case of a student's personal notes taken during a lecture.

3.5.2 Applying Work Action Analysis to a Course

The method outlined above to create a WAA model can be followed when modeling a course. A specific WAA for the planning and formative evaluation of an undergraduate engineering course will be presented in chapter five.

As noted earlier, it is possible to build a pool of templates of typical tasks and situations in a system. The similar patterns followed by many undergraduate engineering courses can be part of this pool that modelers can draw on as needed for new courses. For example, Figures 14 to 17 portray one common pattern, namely, an assignment focused on learning one concept to the different levels of learning identified by Bloom. The pool of templates may also serve as a mechanism for suggesting and portraying new pedagogies to faculty. Also, the model of a course taught in previous semesters can provide much guidance on how to model that course in a new academic term.

3.5.3 Aspects of Courses Captured by Work Action Analysis

One major benefit of WAA is having a detailed and comprehensive view of the course. This reveals how all the elements in the system are related and support each other, and ultimately how all those elements support the overall goals of the course. The structure of the WAA framework reveals the relations between the levels of abstraction and levels of granularity, and how the atomic elements only relate to the course goals by supporting the physical actions and cognitive activities. This translates into very specific guidance for the instructor, e.g., revealing the atomic elements that are required and ensuring that the depth of learning required for the assignments meet their learning objectives for the course.

3.6 Comparison of Work Domain Analysis and Work Action Analysis

WAA draws heavily on the framework of the abstraction hierarchy and part-whole decomposition from work domain analysis. The major difference between the two in terms of their modeling frameworks is that work domain analysis captures only constraints in the environment while WAA identifies both environmental and cognitive constraints. This distinction is based on the difference in their purposes and requires the differentiation between the types of relations used between the levels in each framework. The corresponding differences in method and model have been noted throughout and are summarized in this section.

As noted in chapter two, work domain analysis represents functions between physical objects and goals in the levels of abstraction. Functions refer to potential actions within the work domain, but not the actual performance of an action by the agent. Elements at the level of functions are "*independent* of the underlying processes involved as well as their physical implementation" (Rasmussen et al., 1994, p. 38-39, italics theirs). Since WAA considers the performance of the action by the agent in relation to the environment, actions replace functions in a means-end hierarchy to show they are what manipulates the objects in the domain.

The inclusion of cognitive constraints in WAA requires a different type of relation between levels of abstraction than is used in work domain analysis. Both frameworks are hierarchical in nature and the nature of a hierarchy is defined by the relations between its levels (Vicente, 1999). Work domain analysis uses structural means-end relations between levels, as described in chapter two. The means-end aspect of these relations means they connect two elements where one refers to a desired end or goal and the other refers to one means to accomplish that goal. The structural aspect of these relations refers to them relating two items that are a part of the physical structure of the system.

As WAA includes environmental and cognitive elements, it uses means-end relations, but not structural ones. The agent-environment means-end relations used in WAA show that these relations connect the cognitive constraints that immediately drive actions to the elements of the environment that heavily influence actions in a means-end fashion.

Another difference between work domain analysis and WAA is how each represents the roles of cognitive agents. Work domain analysis has captured different roles in one of two ways. First, separate columns can be added orthogonal to the means-end dimension where each column represents the work domain of one role. However, this precludes the use of a parts-whole dimension for analysis within a two-dimensional representation. Also, this completely separates the roles without showing how they interact with each other. Second, the single work domain can have sections identified as the responsibility of a particular role (see Figure 2). This approach assumes that both roles are working in the same work domain and striving for the same overall goals, which may not be the case. While this method can show where two roles overlap in a work domain, it does not represent how they interact. When representing the work domain, it is necessary to include all the potential functions in that domain for any role. However, actions are performed by individual agents. In many systems there will be sets of actions performed by only one role, or, one role may assign actions to another. For example, instructors assign work to students, yet they are both roles in the system of a course. In addition, each role may have a set of objectives that are associated only with that role, such as a student's objective of achieving a high grade in the course. Thus, while in many cases it is possible to represent distinct roles in a single representation in work domain analysis, WAA makes separate representations for each role to have its own two dimensional means-end and parts-whole framework. This allows the modeler to better identify the system elements that influence a single role. Also, while the roles are treated as distinct in WAA, they are not isolated. The correspondence relations that exist between the roles show how they influence each other.

3.7 Summary of Work Action Analysis

WAA is intended to support design and evaluation of learning service systems by providing insight into how the environment, physical action, and cognition interact in this class of systems. WAA models are qualitative as they capture the elements at the different levels of abstraction and granularity, and the means-end, parts-whole, and correspondence relations between them. As has been noted, WAA models do not favor the cognitive or ecological approaches to determining what drives behavior. Rather, WAA recognizes the influence of both environmental and cognitive constraints in shaping the behavior of cognitive agents. As such, it shows the influence inside-out of a cognitive agent's goals on behavior and shows the outside-in influence of the constraints of the environment on behavior. This allows the WAA model to capture both the internal objectives and external influences that drive learning in a learning service system.

The WAA modeling framework includes four levels of abstraction: atomic elements, physical actions, cognitive activities, and agent objectives. These four levels are based on the original levels identified by Rasmussen (1985) as the levels of abstraction at which people think about their work tasks. The specific levels used in WAA are based on the nature of learning service systems and the need to capture both cognitive and environmental constraints, as discussed in sections 3.2.2 and 3.3.1.1. The parts-whole dimension used in work domain analysis to decompose the system in to parts relevant for the analysis is used for the same purpose in WAA, but may be based on natural groupings in time in addition to physical space.

WAA also examines multiple roles of cognitive agents since learning service systems by definition must have at least two different roles of agents. This makes it necessary to identify how the roles are related, which is discussed in section 3.3.1.3.

WAA can support the planning evaluation of a system during design to determine how well the system goals will be met by the specified objects, physical actions, and cognitive activities. The designer (or evaluator, if a different person) can use WAA to create a representation of the system. This representation can then be used to judge the alignment within roles; that is, whether the atomic elements are sufficient to carry out the physical actions, whether the physical actions are sufficient to accomplish the cognitive activities, and whether the cognitive activities are sufficient to achieve the objectives. This representation can also be used to test alignment between roles via correspondence relations. Work domain analysis has been used for what is essentially planning evaluation in other domains (Naikar & Sanderson, 2001). The similar framework of WAA can also be used for this purpose, yet will be more effective for learning service systems. This evaluation can then feed back into the design process to adjust the design appropriately.

Part of using WAA for planning evaluation is making the evaluator's mental model of the course explicit. In the process of making his/her mental model explicit, the evaluator must confront inconsistencies in the model and notice parts of the model that are not comprehensive or are missing. By going through a method to make a model such as the one described in this chapter, the evaluator will actually inform his/her own mental model of the system, leading to a better sense of the key elements in the model, their interactions, and how roles influence each other to meet the course objectives.

In addition, WAA can be used to support formative evaluation of a currently functioning system. A WAA model can be made of the system before or during implementation to serve as an interface to evaluate the system. This interface can include measurements taken on system elements of interest. The measurements can be compared to what was expected, and if the data shows the system is not functioning as expected, the model and measures should reveal what atomic elements, physical actions, and/or cognitive activities are not contributing to the system goals as expected. The model can then be used to reason through where the specific problem exists in the system. In this, the model informs the evaluator's reasoning of how the system works so the measures can be interpreted in that context. This use is similar to the use of work domain analysis in ecological interface design described in chapter two.

Another aspect of systems where a WAA could bring insight is in externally prescribing actions. Procedures that designate actions for workers in a given situation are used in many domains. In many work situations, actions are prescribed to one agent by another agent being modeled or by an entity outside the model. For example, in education the instructor prescribes many actions for students to accomplish through distributing atomic elements such as assignments. Students' behavior may also be driven by role objectives from external sources, such as honor codes, and objectives from internal sources, such as the joy of learning. An analysis of the prescribed action can be performed in relation to the atomic elements and role objectives to determine how well the prescribed action will meet the objectives and whether the necessary elements exist in the system. A different approach is to trace from any action to the atomic elements and role objectives to determine how each influences that action and the source of that influence.

In developing WAA, including the model framework (section 3.2.3), a method for creating a model (section 3.4), and showing how that method applies to education (section 3.5) the first objective for this dissertation "develop a modeling framework, work action analysis, that can be applied to learning service systems, such as education" has been accomplished.

CHAPTER 4

COLLECTING EVALUATION MEASURES VIA A COURSE MANAGEMENT SYSTEM

4.1 Motivation

As noted in chapter two, evaluation cannot be done through measures alone but with measures and a model for interpretation. The structure of a system's environment significantly shapes and constrains behavior (Kirlik, 1995). For example, students exhibit different behavior in a course with weekly homework assignments and four exams as compared to a course where the only graded assignment is a design project due at the end of the semester. The same is true for a course website, where student behavior is constrained by the functions and content available. Even among course websites using the same CMS, different instructors may have different pedagogical approaches and choose to use different functions of the CMS. Thus, it is important to consider the context of the course when performing an evaluation and determining the meaning of a measure.

Considering the measures in the context of the course is difficult as the measurements are typically not all collected into one interface. This is true of all measurement tools implemented independently of a course website, such as WebAssign, but it is also true of many CMSs. In WebCT, for example, student grades are accessed through one system component, on-line quizzes and their results through another, and student paths through the material are tracked in a third. There is no one interface in WebCT where all types of measures that can be used for evaluation are collected, though this should be possible since all this data is stored electronically in the same CMS.

4.2 Internet-based Measurement for Evaluation

In chapter one, the use and advantages of a CMS as part of a course are discussed, particularly with respect to the task of evaluation. One characteristic of a CMS is the ability to build evaluation measurements into the system. Using a CMS for evaluation has several advantages over traditional paper-based methods. First, the Internet allows students to be measured while they are widely distributed temporally and geographically. Any time students are accessing the CMS their activities can be measured, so that evaluators are not tied to evaluations distributed in a single class session that use class time and cannot measure students that are absent. Another advantage is that Internet-based measurements are collected electronically and can be automatically scored and analyzed. For example, data can be collected through an HTML form and sent to a script for processing and storage. Likewise, the results can be displayed electronically through the web or e-mail. Finally, when a course already uses a CMS, it is part of the normal course activities. Thus, electronic measurements can be integrated into the current work practices.

These qualities of implementing measures through a CMS would be beneficial to a formative evaluation. Evaluation data can be collected and analyzed in closer proximity to the aspect of the system being examined so changes can be made quickly. Also, the time and resources required to administer and analyze measures for formative evaluation would be reduced, freeing the evaluator to spend more time developing measures or for other tasks. In the survey of engineering instructors reported in chapter two, the instructors reported that their three major hindrances to performing more evaluation activity were the amount of time available for those activities, difficulty in getting information from students, and a lack of effective, available tools (Nickles et al., 2001). In addition, 89% of engineering professors reported using the surveys provided by the university or college for evaluation, the only measurement to be used by more than 50% of all respondents. Often these surveys are created and analyzed by the university or academic unit and the instructor simply encourages students to participate and receives the results. This suggests that, while they have difficulty locating or developing their own effective measures, instructors will use measures that are provided to them. Thus, by making electronic measures available through the CMS instructors are already using, practical barriers to formative evaluation can be removed.

A number of measures were described under each of the three categories presented in chapter two. Each of these can be implemented through a CMS to support formative evaluation. In implementing measures through a CMS, it must be remembered that a variety of course formats may use the CMS for support. Thus electronic measures must be designed so they can be adapted to a wide variety of pedagogical methods. Also, measures from each of the three types should be implemented to support evaluation of a variety of learning activities.

4.2.1 Centralized Evaluation Component

As noted earlier, existing CMSs collect some evaluation data, but that data is typically not collected, automatically analyzed, and presented in one place in the CMS. A centralized evaluation component can be developed in a CMS so that the evaluator can consider the results of all the measures in parallel with a system model. At the least, this interface to the measurement data can be used in conjunction with the evaluator’s mental model. If a representation of a model of the course is available in the interface and is annotated with the measures, this can provide even greater support to the evaluator's judgment. As shown by ecological interface design noted in chapter two, bringing the model and measures together in an interface can bring significant benefits to the task of evaluating a system.

4.3 Demonstration of Centralized Evaluation Component

To demonstrate the design concept of a centralized evaluation component, at least one measure from each of the three categories described in chapter two (performance, perception, and process) has been implemented in a CMS. The CMS used as a testbed is ITWeb, a CMS developed and implemented in the School of Industrial and Systems Engineering at Georgia Tech. ITWeb is written in the scripting language PHP using a MySQL database for data storage. It currently runs as a virtual domain (itweb.isye.gatech.edu) on the Apache-based web server of the School of ISyE. ITWeb is designed to deliver an integrated curriculum where instructors and students can see links between topics within and between courses in the curriculum (Pritchett et al., 2002). Each measurement tool in the evaluation component is described below, followed by a discussion of the centralized evaluation component as a whole. A description of an earlier version of the evaluation component of ITWeb and its technical details are described in (Nickles & Pritchett, 2002). All screen captures used here to show ITWeb are a contrived example. This is done to avoid displaying any data from students that have not consented to participate in the ITWeb research project and so release their data publicly.

4.3.1 Perception Measures

As described in chapter two, perception measures capture student opinions about their learning. ITWeb implements two perception measures, surveys of students and content ratings, which are described below.

4.3.1.1 Surveys of Students

Surveying students is a widely used evaluation measure that can be used in a CMS. The first major question considered when developing electronically delivered surveys for ITWeb was what elements of the course will be examined. ITWeb is designed so that topics are a primary focus and structure of courses, thus, topics are the level at which the evaluation system collects data.

The second major design question considered when developing surveys in ITWeb was whether to prescribe generally applicable surveys or to provide the instructor with tools to create their own surveys. This decision must be made based on the purpose of the surveying system. For example, if the major purpose is to compare the aspects of the course being evaluated across topics and courses, then the same surveys should always be used. This implementation chose to provide the evaluator with tools to create their own surveys and providing suggested questions to use in those surveys. Evaluators are given the freedom to choose the same questions for every survey, or to tailor the questions to the material.

The third major design question was what types of questions and responses would be available in ITWeb surveys. There are many structures that can be used for survey questions: e.g. free form, Likert or other ratings scale, multiple choice, and true/false to name a few. If evaluators create their own surveys, the electronic survey system should support enough types to provide a wide range of questions, yet it must balance this against the requirements for programming and data storage for a variety of question types, and the apparent complexity, to the evaluator, of creating a survey. These are balanced in ITWeb by providing three types of survey questions: 5-point Likert scale, multiple choice, and free response. The Likert scale questions allow the evaluator to enter a statement and students are presented with five choices: strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, and strongly agree. Multiple choice questions allow the evaluator to enter a question and enter up to five possible responses from which students can select. Evaluators are not required to use all five responses. Free response questions allow the evaluator to enter a question and students may respond with a string of text.

ITWeb allows the evaluator to administer to students a survey associated with any topic in the course. To create a survey, the evaluator navigates to the centralized evaluation component for the course and selects the topic to be examined (Figure 18). The evaluator then selects the option of creating a new survey for this topic. Multiple surveys can be created for any topic. On the interface to create a new survey, the evaluator can select up to five questions to include in each survey. For each question, the evaluator chooses the type and text of each question and supplies allowable answers (for multiple choice questions) (Figure 19). Also, the evaluator sets a date after which the survey will be presented to students. The evaluator can also enter the expected answer from students, which will be used during analysis. Some questions are also suggested for the evaluator, and these can be chosen instead of evaluator created questions.

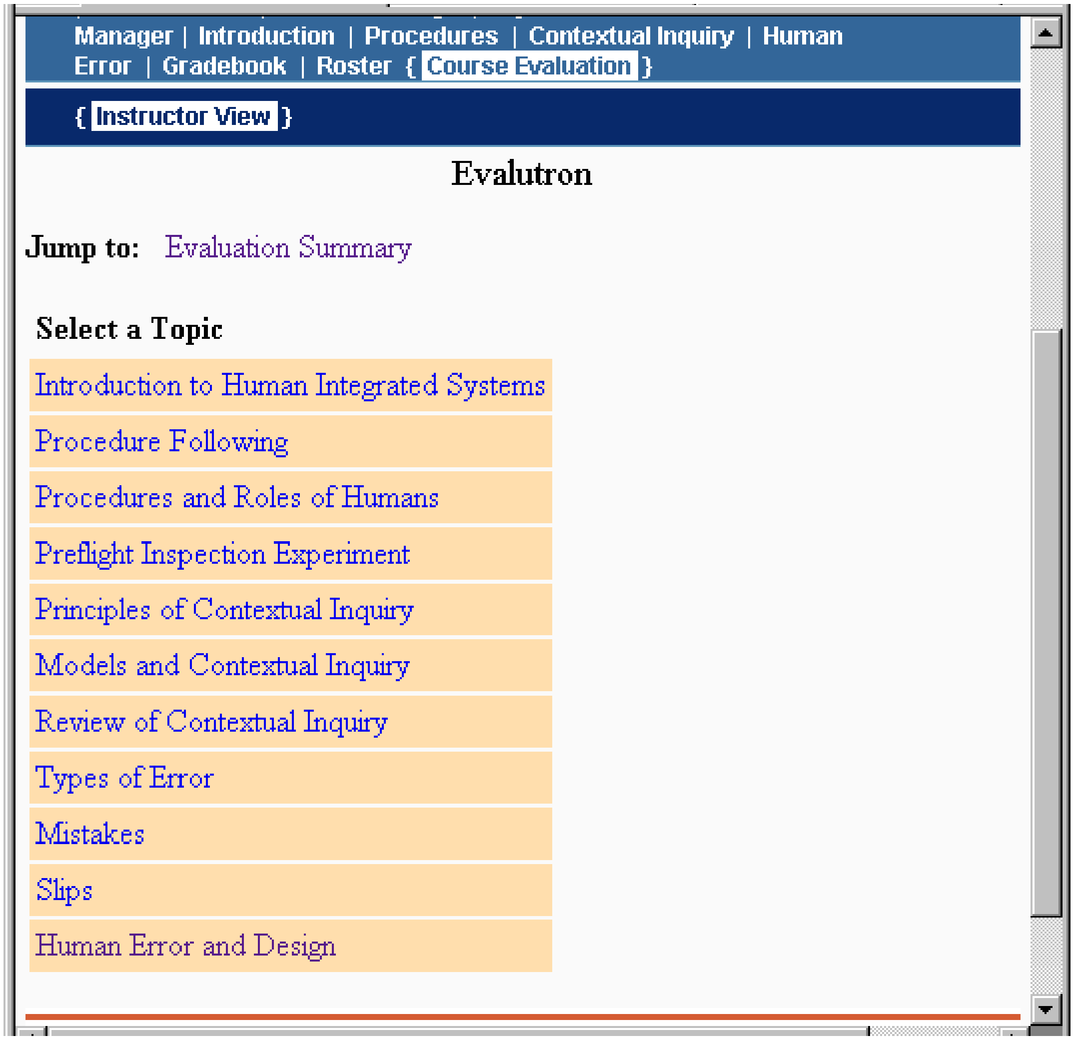


Figure 18: ITWeb Evaluation Component - List of Topics

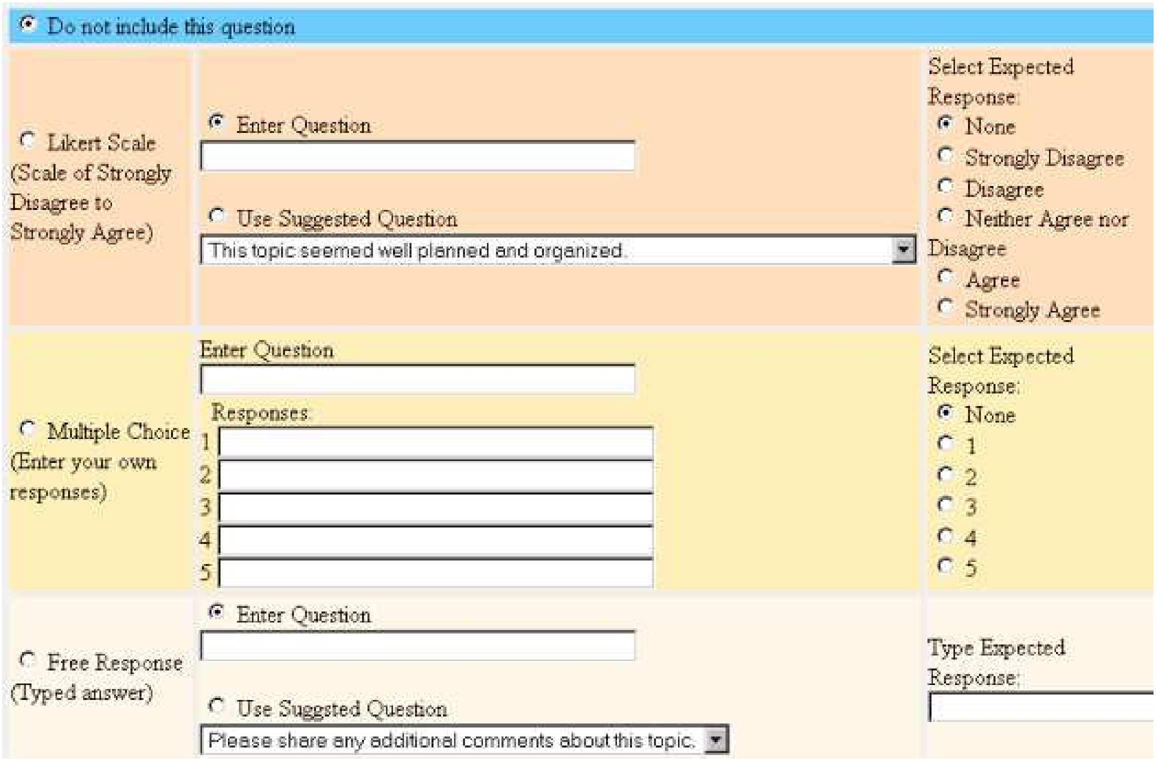


Figure 19 : ITWeb Evaluation Component - Survey Questions

When the evaluator submits the survey, the settings are stored in ITWeb's MySQL database. One database table stores the main record of the survey, including such information as the course and topic to which the survey is attached, who created the survey, when the survey should be released, and pointers to the records of the questions. The questions are stored in a separate table, one per record. Each question record stores a pointer back to the main survey record, the question text, the question type, allowable multiple choice responses, and the expected response. Once a survey is stored in the database, it cannot be altered through ITWeb. This is to prevent the survey questions from being changed after some students have taken the survey and before others will also respond, thus essentially implementing two different surveys. Suggested survey questions are also stored in the database and shown to the evaluator when creating a survey.

Once the survey is stored in the database, five conditions must be met for it to be presented to a student in the class:

- the student must visit the course homepage,
- the student must not have responded to the survey yet,
- the current time must be past midnight of the day set for release of the survey,
- the current time must be past midnight of the day after its corresponding topic was covered with the class, and
- if the student has been presented with the survey before and clicked on "Ask me later" rather than responding, then it must be at least one hour since the student was last presented with the survey.

The function to display the survey is located only on the course homepage. The student may be registered for more than one class in ITWeb, and each class may have surveys for the student to respond to. The display of the survey is delayed until the day after the topic was covered in lecture to pace the progress of the course.

To display a survey, ITWeb uses JavaScript to open a new browser window in front of the current ITWeb window (i.e., a "pop-up" window) to present the survey to the student (Figure 20). If there is more than one survey to be presented to students, the survey that was released earliest is presented. This window displays the survey questions from the database and two options for students. If the student does not wish to respond at this time, the "Ask me later" button delays the presentation of this survey for at least one hour. The other option allows students to submit responses. Either option creates a record in another database table recording the student's ITWeb user number, the time of the response, the type of response (submitting answers or delay until later), and the responses to the questions. The available responses to the Likert scale and multiple choice questions are presented by HTML radio buttons, allowing only one response per question. Free response questions are presented with an HTML text box to enter a response. The radio buttons on the student's survey are not set to have a default, and there is no default text in the textbox for free response questions. Thus, if a student submits the survey with no responses, they are recorded as having examined the survey but their data is not included in the analysis of the survey responses.

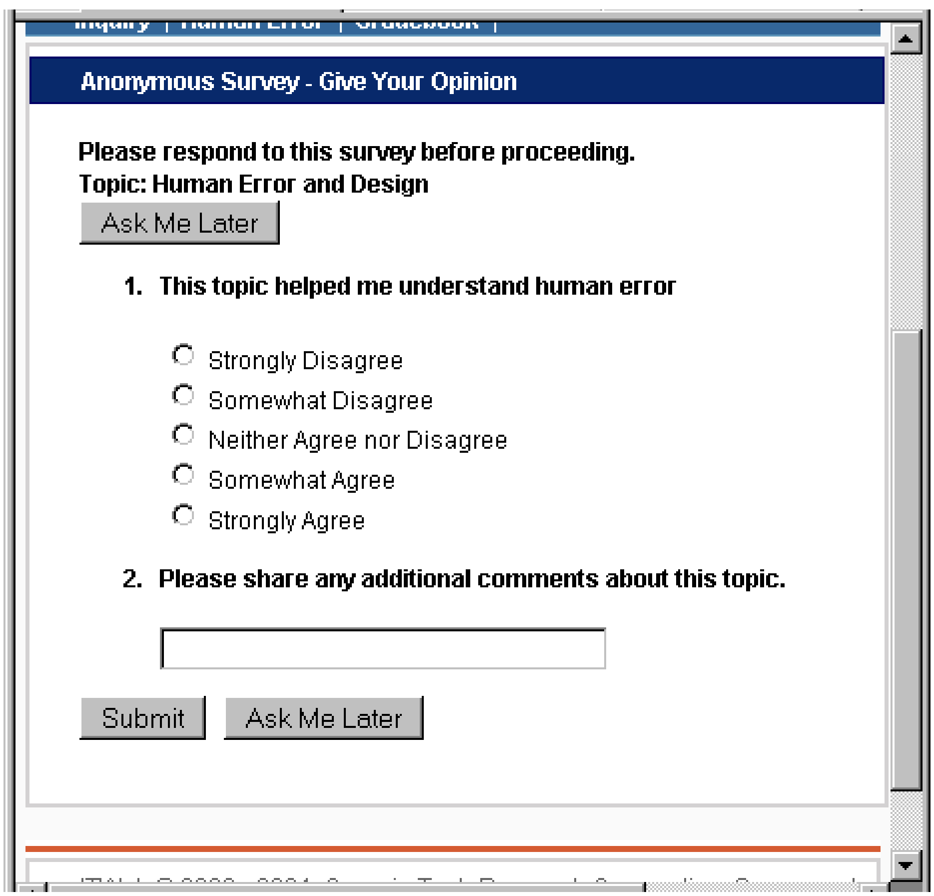


Figure 20: ITWeb Evaluation Component - Survey as Displayed to Students

At any time, the evaluator can go to the evaluation interface for the topic (as described above) and view the current results for this survey (Figure 21). The evaluation system calculates the response rate for this survey based on all the students that chose the “Submit” button. Details on the responses to each question are then presented, including the original question and the expected answer, if recorded. For Likert scale and multiple choice questions, the evaluation system determines how many students responded to each possible answer and calculates the percentage of students that responded to each answer out of all those who responded to the question. If an expected answer was provided, that response and its data are shown in a green font as opposed to black for the others. Also, a JPEG image of a bar chart is generated to show the responses to the question graphically. For the free response questions, the question and expected answer are displayed, along with all the unique responses by students. A regular expression is used to compare each student answer with the expected answer, testing only for an exact match. If there is an exact match, that response is displayed in a green font. Also, a regular expression is used to compare each student answer with each other, testing for an exact match. Each unique response is listed with a count of the number of students that gave that response.

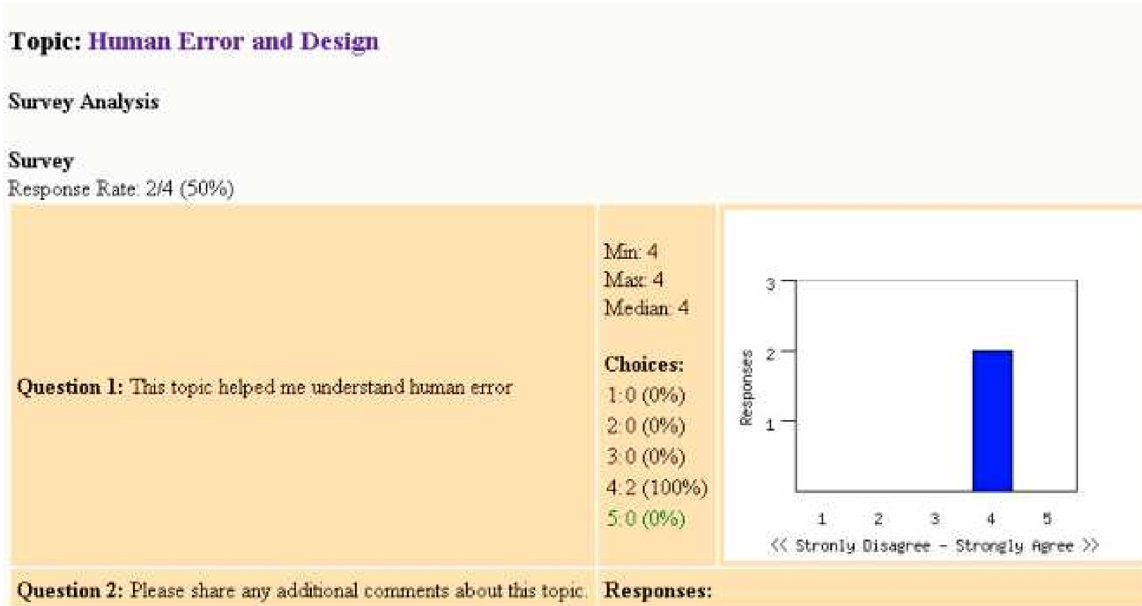


Figure 21: ITWeb Evaluation Component - Survey Results

This data and analysis is presented in "real time," that is, all responses up until the time the evaluator views the survey results interface will be displayed. Also, no information linking individual responses back to individual students is displayed to the evaluator; the survey results are presented anonymously.

4.3.1.2 Content Ratin gs

In addition to surveys, students can give feedback on the effectiveness of the electronic materials attached to each topic. This provides a means to examine the student's perception of the topic material as a whole in a way that is less intrusive than surveys. The content ratings employ the question: "Considering everything, how do you rate the effectiveness of this material?" The student can respond to this question with one of five responses: very ineffective, ineffective, partly effective partly ineffective, effective, and very effective. Using the same question and rating scale allows comparisons to be made between the material used for various topics. While this method of measurement is less intrusive than the surveys, students must take the initiative to rate the material so there is greater potential for bias and for a lower response rate in the content ratings than in the surveys.

When entering a new topic, the instructor can set whether or not to allow students to rate its materials. This setting is on by default and can be changed at any time by the instructor. When it is set on, every time a student views the page for a single topic, a colored box is also displayed allowing the student to respond to the content rating question (Figure 22). A group of HTML radio buttons are used to allow only one rating to be selected, and no response is set as the default. When the student clicks the "Submit Rating" button, they are taken to an interface where they can confirm their selected rating (if they selected one) and are provided with an HTML text area where they can leave text feedback for the evaluator about this material (Figure 23). The purpose of this is to provide students with a way to express what aspects of the material were helpful or not and why. Students may choose to either "Just Submit Rating" or to "Submit Rating With Comment." When the student clicks a submission button on this interface, ITWeb stores this rating and any comments in a database table. Each record includes the user number for the student, the identifying number for the topic, the rating, any comments the student made, whether or not this rating is the "active" rating, and a timestamp. A rating that is "active" is the rating that was last recorded by this student for this topic. Students may rate topics multiple times and each is stored in the database; however, only the latest rating is included in the analysis for the evaluator.

Figure 22: ITWeb Evaluation Component - Topic Rating Box

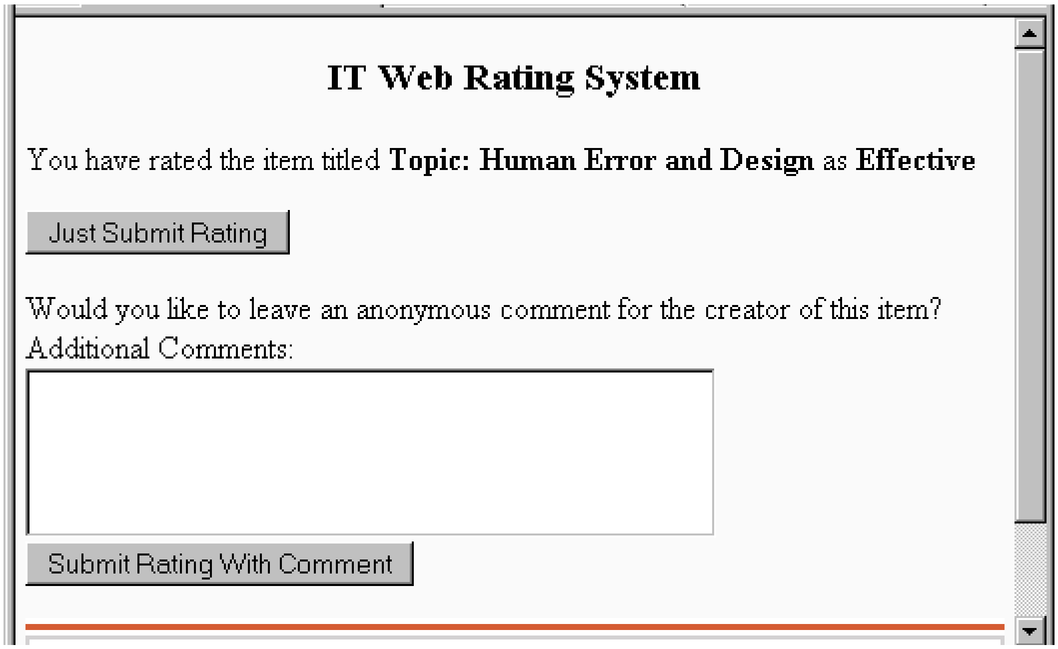
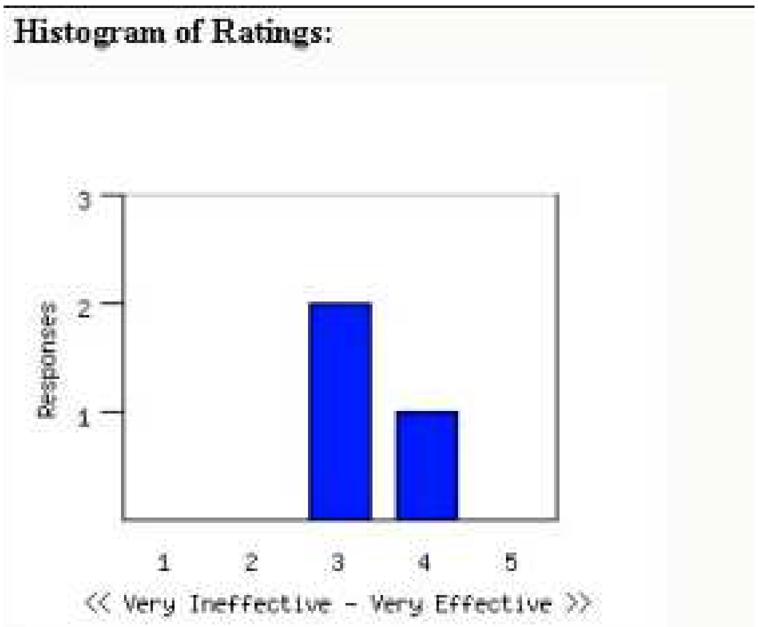


Figure 23: ITWeb Evaluation Component - Topic Rating Comments

At any time, the evaluator can view the current results of the content ratings in the evaluation system. Similar to the Likert scale and multiple choice questions in the survey results, the number of responses to each rating level are presented as a bar graph (Figure 24). In addition, the minimum, maximum, and median ratings are calculated and displayed (Figure 25). Student comments are displayed along with the date they were left for the evaluator. Like surveys, all responses are presented anonymously to the evaluator.



User Comments

Comment	Date
Order of the slides could be more logical	03/31/2004
didn't flow well, maybe re-organize?	03/31/2004

Figure 24: ITWeb Evaluation Component - Rating Results Graph and Comments

Topic: Human Error and Design

User Rating Analysis

Summary Statistics
Question: Considering everything, how do you rate the effectiveness of this material?

Statistic	Value
Total Ratings on this item	3
Min	Partly Effective, Partly Ineffective
Max	Effective
Median	Partly Effective, Partly Ineffective

Figure 25: ITWeb Evaluation Component - Rating Results Response Summary

4.3.2 Performance Measures

In addition to perception measures, ITWeb facilitates the collection of performance measures in the form of student assessments. In addition, ITWeb has a separate component, the gradebook, for delivering assignments and grades to students. The gradebook is not integrated with the evaluation component and is not anonymous, but it is useful for evaluation. The following sections describe the mechanism for administering ungraded student assessments and the gradebook.

4.3.2.1 Student Assessments

Assessing student learning is one type of performance measure that can be implemented in a CMS. The design of student assessments in ITWeb is very similar to that of the surveys. As with surveys, each assessment examines one topic. Also, like surveys, ITWeb instructors have tools to create their own assessments. There are no suggested questions provided with assessments as there can be a wide range of subject matter and desired levels of learning in the courses using ITWeb.

Assessments differ from surveys in the types of questions they require. For example, questions with rating scales are likely not appropriate for assessing student learning. Thus, three types of questions were chosen for student assessments in ITWeb: true/false, multiple choice, and free response. The true/false questions allow only one of two possible responses (true or false). Multiple choice questions allow the evaluator to enter a question and up to five possible responses from which students can select. Evaluators are not required to use all five responses. Free response questions allow the evaluator to enter a question and students may respond with a string of text.

The implementation of student assessments in ITWeb is similar to that of surveys. To create an assessment, the evaluator goes to the centralized evaluation component for the course and selects the topic to be examined. The evaluator then selects the option of creating a new assessment for this topic. The interface to create an assessment is similar to that used to create surveys. The evaluator can create up to five questions to include in each assessment, including setting the type and providing allowable answers and the correct answer (Figure 26). The evaluator also sets a date after which the assessment will be presented to students.

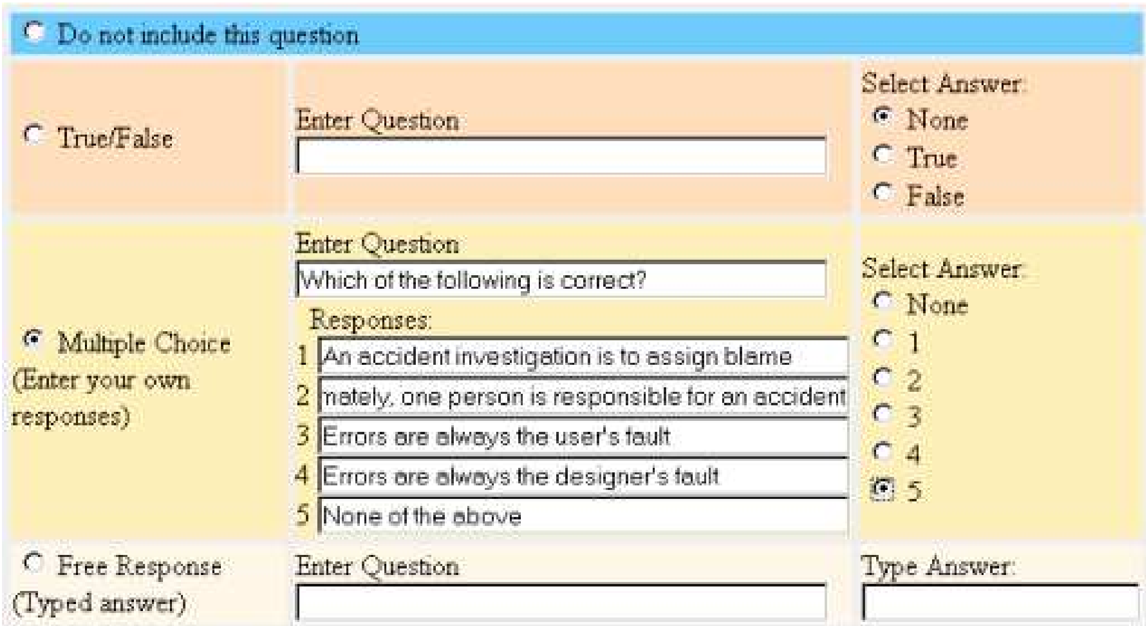


Figure 26: ITWeb Evaluation Component - Assessment Questions

When the evaluator submits the assessment, the settings are stored in the ITWeb database in different tables than those for surveys. One database table stores the main record of the assessment, including such information as the course and topic to which it is attached, who created the assessment, when it should be released, and pointers to the records of the questions. The questions are stored in a separate table, with the question text, the question type, allowable multiple choice responses, the expected response, and a pointer back to the main assessment record. Like surveys, once an assessment is stored in the database, it cannot be altered within ITWeb.

Once the assessment is stored in the database, the same five conditions that are used to determine when to display a survey are used to determine when to present an assessment. Only one survey or assessment is displayed at a time to the student. If there is at least one assessment and at least one survey, the assessment associated with the topic with the oldest coverage date is selected.

When these conditions are met, ITWeb uses JavaScript to open a new browser window in front of the current window displaying ITWeb (i.e., a “pop-up” window) (Figure 27). This window displays the questions from the database and two options for students. If the student does not wish to respond at this time, the “Ask me later” button can be used to delay the presentation of this assessment for at least one hour. The other option is to submit the student’s responses to the questions. Either option creates a record in another database table containing student responses. Records in this table record the student’s ITWeb user number, the time of the response, the type of response (submitting answers or delay until later), and the responses to the questions. The responses to the true/false and multiple choice questions are presented using a group of HTML radio buttons, requiring only one response from students. Free response questions are presented with an HTML text box to submit a response. The radio buttons are not set to have a default, and there is no default text in the textbox for free response questions. Thus, if a student submits the assessment with no responses, they are recorded as having filled out the assessment but their data is not included in the analysis.

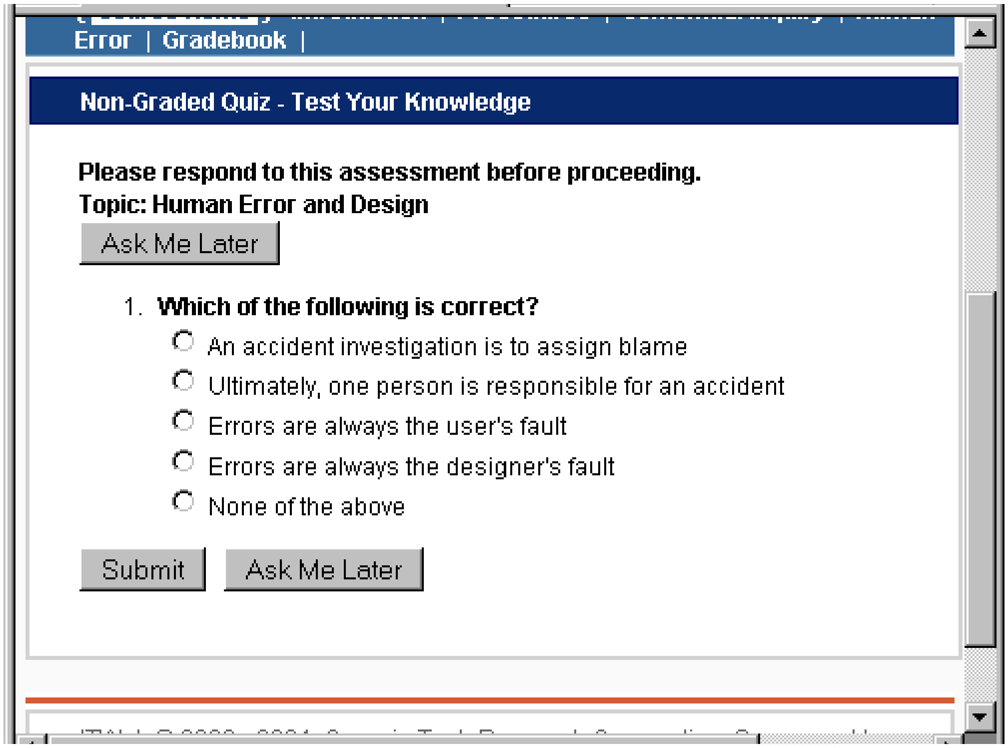
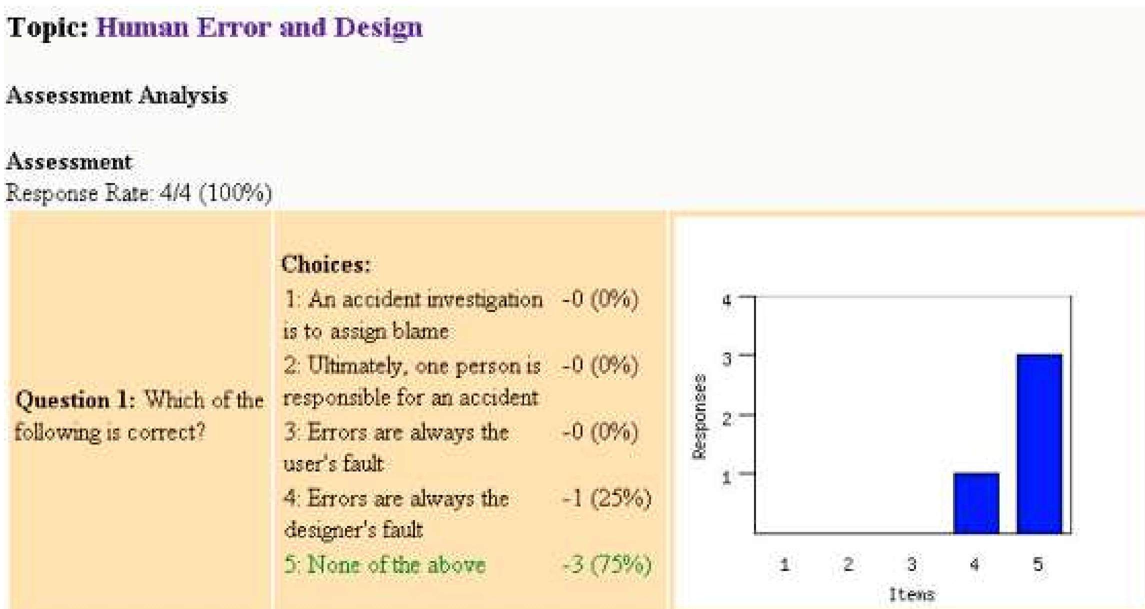


Figure 27: ITWeb Evaluation Component - Assessment as Displayed to Students

At any time, the evaluator can go to the interface for this topic in the evaluation system (as described above) and view the current results for this assessment (Figure 28). The evaluation system calculates and displays the response rate for assessments. Details on the responses to each question are then presented, including the original question and the expected answer. All results are presented anonymously. For true/false and multiple choice questions, the evaluation system displays the number of responses for each allowable answer and the percentage of students that responded to each. If an expected answer was provided, that response and its data are shown in a green font as opposed to black for the others. Also, a bar chart is generated in a JPEG image to show the responses to the question graphically. For the free response questions, the question and expected answer are displayed, along with all the unique responses by students. A regular expression is used to compare each student answer with the expected answer, testing only for an exact match. If there is an exact match, that response is displayed in a green font. Also, a regular expression is used to compare each student answer with each other, testing for an exact match. Each unique response is listed with a count of the number of students that gave that response.



Topic: Human Error and Design

Assessment Analysis

Assessment
Response Rate: 4/4 (100%)

Question 1: Which of the following is correct?	**Choices:**	
	1: An accident investigation is to assign blame	-0 (0%)
	2: Ultimately, one person is responsible for an accident	-0 (0%)
	3: Errors are always the user's fault	-0 (0%)
	4: Errors are always the designer's fault	-1 (25%)
	5: None of the above	-3 (75%)

Figure 28: ITWeb Evaluation Component - Assessment Results

In engineering education, many questions used to assess student learning will result in a numerical answer. If evaluators wish to include these questions in an assessment in ITWeb, they may do so in one of two ways. First, the evaluator can determine the solution to a question, predict common mistakes made by students and the solutions resulting from those mistakes, and incorporate those as alternate responses to a multiple choice question. Thus, the evaluator can see how many gave the incorrect answers to determine which errors students are making. The second method is for the evaluator to display the question as a free response question, allowing students to input the result of their calculation. This does not prime students with a set of answers, so they will answer what they truly calculated. However, since the evaluation system searches only for exact matches, the evaluator will need to examine all unique responses to determine if they do not match the answer but are correct with discrepancies, possibly due to round off error or numerical precision, or if they do not match and are incorrect.

As with surveys, this data and analysis are available in "real time," that is, all responses up until the time the evaluator views the results will be displayed. Also, no information linking individual responses back to individual students is displayed to the evaluator; the results are presented anonymously.

4.3.2.2 Student Grades on Assignments and Tests

The gradebook component stores all student grades on all assignments that the instructor has entered. Statistics such as the minimum, maximum, average, standard deviation, quartiles, and percentiles (by tens) are calculated for each assignment for the entire class and presented to the instructor. At this time, this information is not integrated with the evaluation component. Also, the information is necessarily not anonymous. However, grades can provide valuable information for evaluation.

There are three types of grades that can be manipulated in the gradebook: assignments, peer review grades, and composite grades. Assignments are intended to be used for any homework assignment, project, test, or other typical graded assessment of students. Peer review grades are grades associated with students' comments in the peer review component. Composite grades are grades that are calculations of other grades, such as averages of all homework assignments.

There are two views of the gradebook available to the instructor, the calendar view and the spreadsheet view. The calendar view (Figure 29) displays all the assignments in the course in the order in which they are due. This allows the instructor to see the order of the assignments and their due dates relative to each other. The spreadsheet view (Figure 30) displays all the assignments in the course in columns, all the students in the course in rows, and all the grades in the intersecting cells. In both of these views, as in all parts of the gradebook, any student's name, any assignment, peer review grade, or composite grade name, and all assignable grades are links to pages displaying information specific to that item.

Assignment	Time Released	Time Due	Grade: avg (N)	Assignment Files	Solution Files	Comments
HW 1	03/06/04 09:00:00 AM	03/13/04 05:00:00 PM	81.25 (4)	homework01.doc	--	Read the instructions carefull...
HW 2	03/14/04 08:00:00 AM	03/21/04 05:00:00 PM	85.00 (4)	homework02.doc	--	
HW 2 - (Peer Review)			78.33 (4)			
HW 3	03/21/04 08:00:00 AM	03/28/04 05:00:00 PM	68.75 (4)	homework03.doc	--	
HW 3 - (Peer Review)			(0)			
Exam 1	03/30/04 05:00:00 PM	03/30/04 05:00:00 PM	(0)	--	--	
Homework Average			78.34 (4)			

Figure 29: ITWeb Gradebook Component - Calendar View

Key: -- = no grade assigned

#	Name	HW 1	HW 2	HW 2 - Peer Review	HW 3	HW 3 - Peer Review	Exam 1	Name	Homework Average
1	Doe, John	95.00	90.00	56.67	75.00	--	--	Doe	86.67
2	Ivanovich, Ivan	85.00	75.00	70.00	70.00	--	--	Ivanovich	76.67
3	Nickles, George	70.00	85.00	93.33	65.00	--	--	Nickles	73.33
4	Schmoe, Joe	75.00	90.00	93.33	65.00	--	--	Schmoe	76.67
Averages		81.25 (4)	85.00 (4)	78.33 (4)	68.75 (4)	(0)	(0)		78.34 (4)

Figure 30: ITWeb Gradebook Component - Spreadsheet View

When the instructor clicks on the name of an individual student, a page is displayed showing all the grades in the system for that student (Figure 31). From here, the instructor can get an overview of this student’s performance. If the grade for an individual student is clicked, the instructor can see details such as the files that student has submitted, any comments the student has left for the instructor, the currently assigned grade, and any comments the instructor has left for the student (Figure 32). The instructor can set or change the student's grade and leave comments on the assignment for the student (Figure 33). Also, on this page, the instructor can override the default dates for this assignment just for this student and can add or modify the grade or comments for the student (Figure 34).

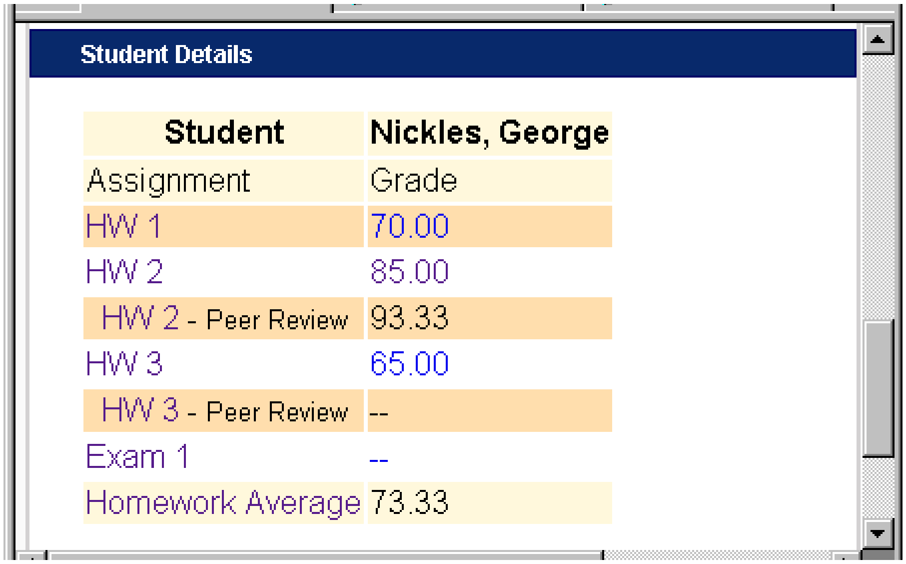


Figure 31: ITWeb Gradebook Component - Single Student View

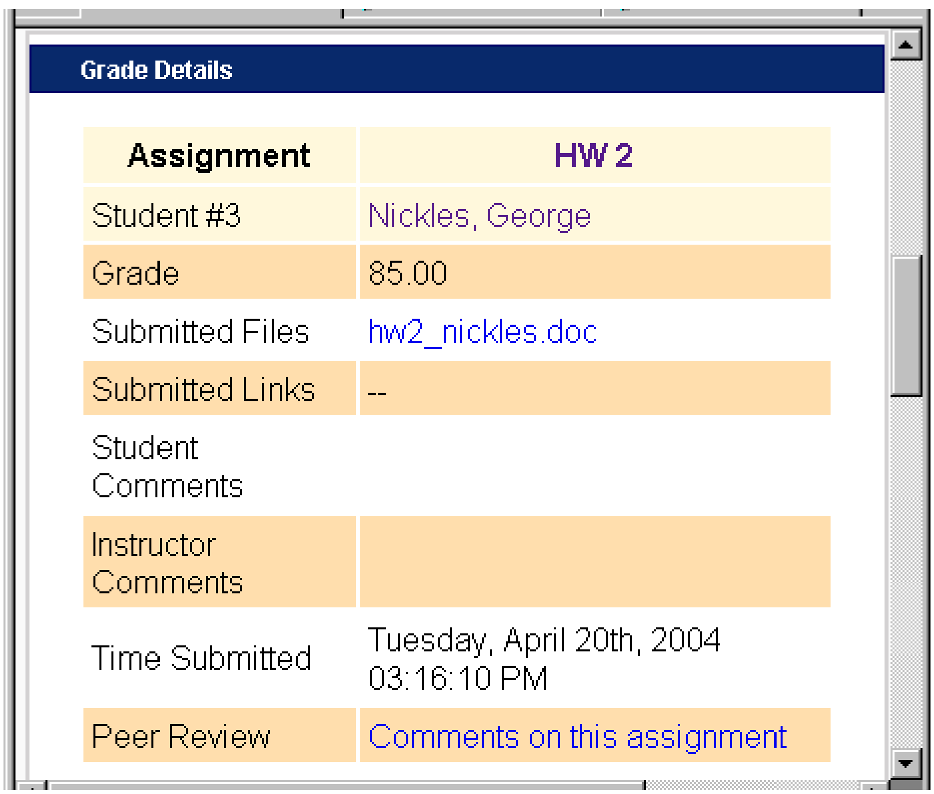


Figure 32: ITWeb Gradebook Component - Single Grade View

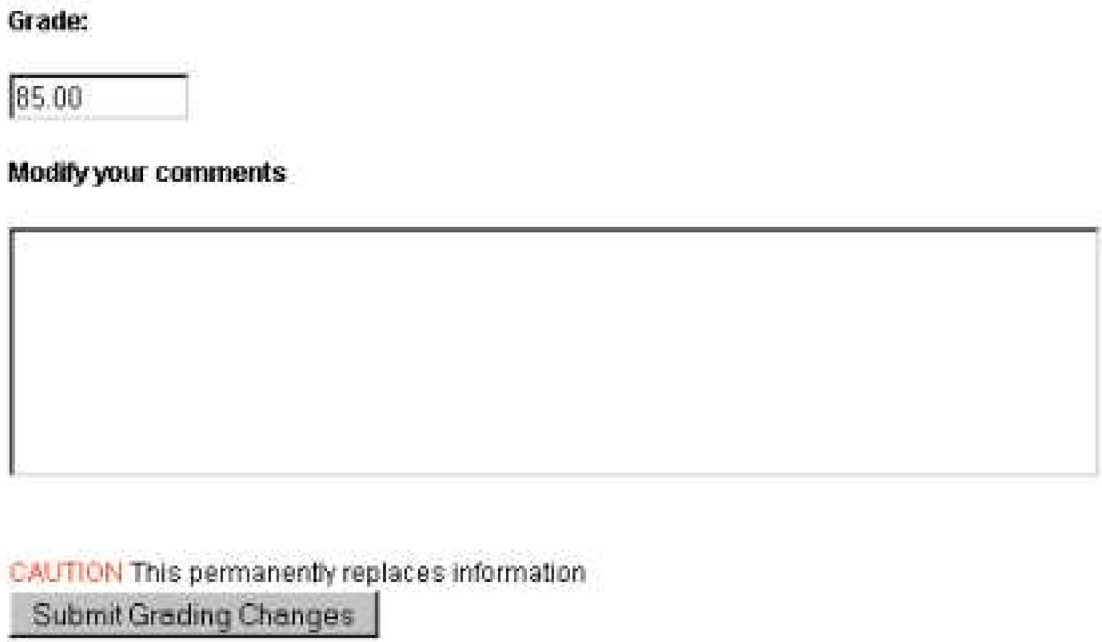


Figure 33: ITWeb Gradebook Component - Modify a Grade

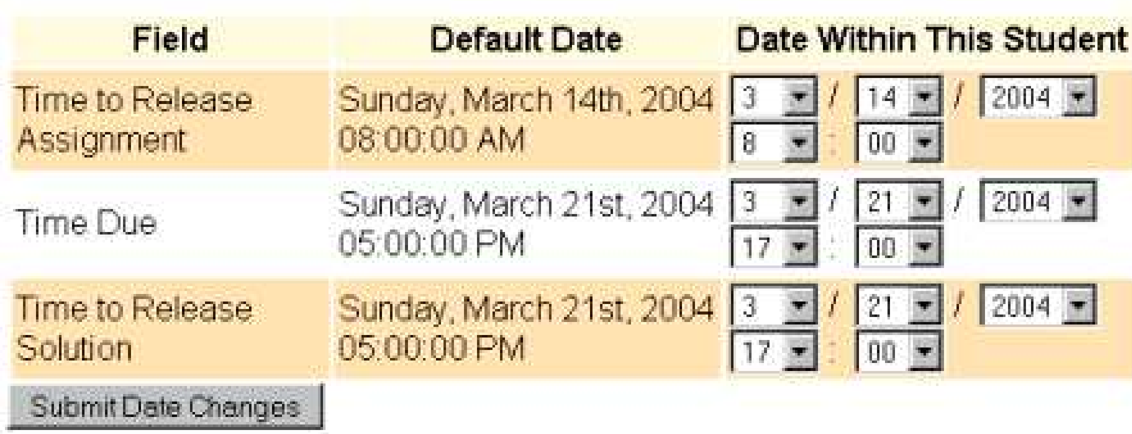


Figure 34: ITWeb Gradebook Component - Modify a Dates for This Student

When an assignment name is clicked, the instructor can view the settings for that assignment, all the current assigned grades, and summary statistics on the grades. Also, the instructor can assign all the grades for the course at once (Figure 35). To create a new assignment, the instructor can click on the appropriate link. This takes the instructor to a page where all the settings for an assignment can be made (see Figure 36). Some items that can be set for an assignment include the files associated with the assignment, the date the files associated with the assignment will be made available to students, and the due date. In addition, topics in the course can be associated with this assignment as the topics it covers. Modifying an existing assignment is done through this same interface.

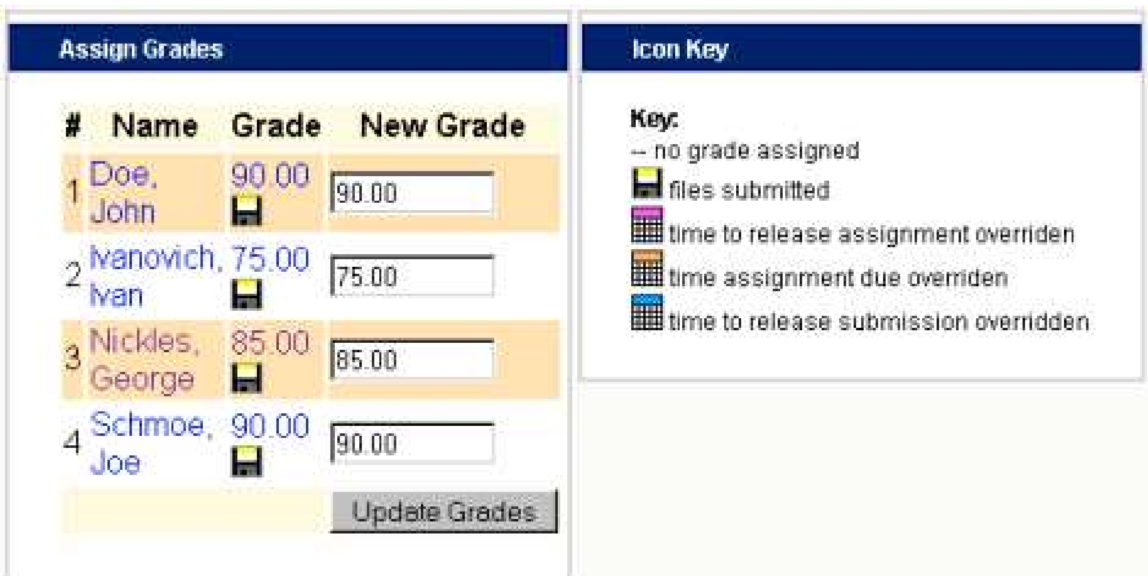


Figure 35: ITWeb Gradebook Component - Set All Assignment Grades

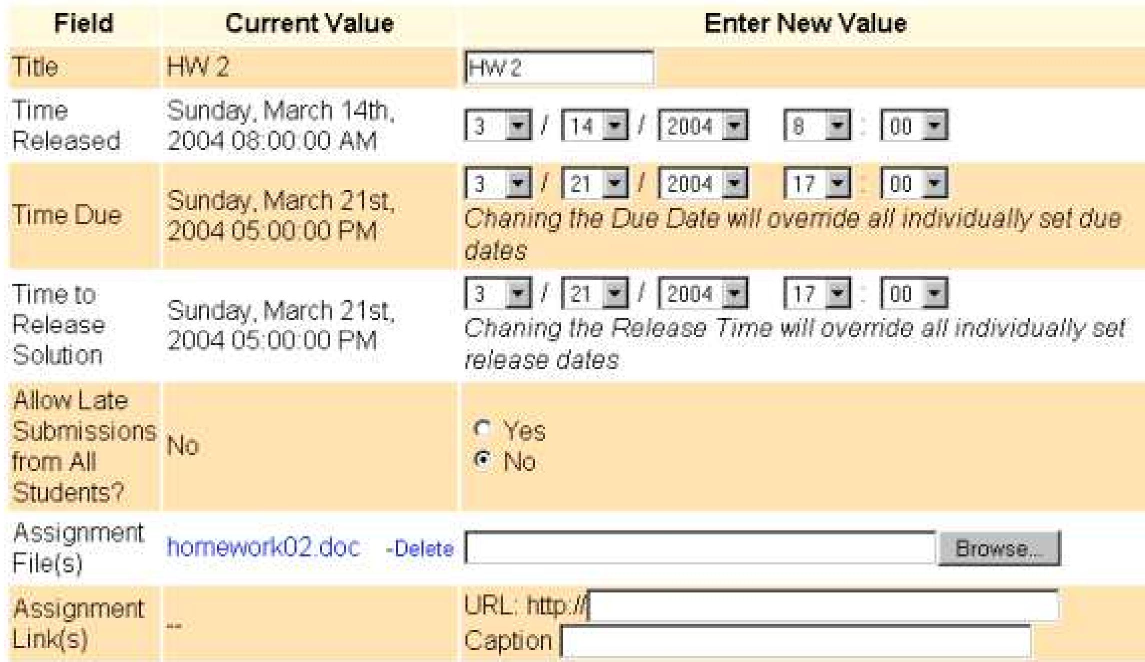


Figure 36: ITWeb Gradebook Component - Create and Modify Assignment

Peer review grades are based on students' comments left in the peer review component. In the separate peer review component, the instructor can allow students to comment anonymously on each other's assignment submissions. The instructor can assign a grade to each student comment and leave feedback for the student who wrote the comment. Peer review grades can be assigned in the gradebook based on:

- the total number of comments students left, divided by X (where X is an integer supplied by the instructor),
- the total number of comments left, up to a maximum value of X, divided by X,
- the sum of the comment ratings, using the highest X comments,
- the sum of all comment ratings,
- the average of all comment ratings, using the highest X comments, and

- the average of all comment ratings.

This grading method is applied uniformly to all students. When the instructor clicks on the name of a peer review grade, ITWeb displays the current grading method, summary statistics, and the individual students' grades (Figure 37). From here, the instructor can go to the page to modify the grading method and the summary statistics that are presented to students (Figure 38).

Grading Method

Assignment	HW 2
Peer Comment Grading Method	Average of Top X Comment Scores
Number of comments X (if applicable)	3
Show Average: 78.33	Visible
Show Standard Deviation: 18.15	Not Visible
Min: 56.67 Max: 93.33	Not Visible
Quartile 1: 63.34 Median: 81.66 Quartile 3: 93.33	Not Visible

Student Grades

Key: -- = no grade assigned

#	Name	Peer Comment Scores (Links go to the comments)	Peer Comment Grade
1	Doe, John	100.00, 70.00	56.67
2	Ivanovich, Ivan	80.00, 70.00, 60.00	70.00
3	Nickles, George	100.00, 80.00, 100.00	93.33
4	Schmoe, Joe	100.00, 100.00, 80.00	93.33

Key: -- = no grade assigned

Figure 37: ITWeb Gradebook Component - Peer Review Grades

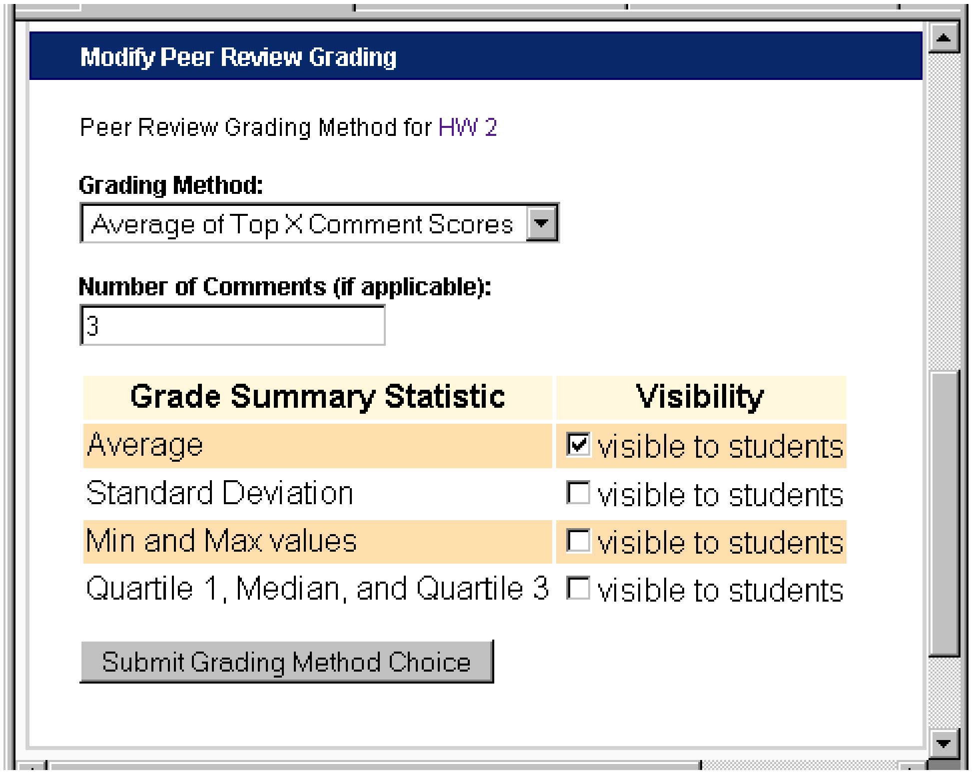


Figure 38: ITWeb Gradebook Component - Modify Peer Review Grading Method

Composite grades allow the instructor to create a grade by selecting other grades in the course and combining them according to four different sets of rules: sum, simple average, proportional (bounded to 100%), and proportional (unbounded). Sum grades take the sum of all other selected grades. Simple average grades average all selected grades, weighing each equally. Proportional grades allow the instructor to specify a decimal proportion for each grade selected, and grades are multiplied by their associated proportion and then added together. Proportional grades that are bounded to 100% require the instructor to ensure that all the decimal proportion values add to 1.00. Unbounded proportional grades do not enforce this requirement. Composite grades can be calculated based on any combination of assignment grades, peer review grades, and composite grades. An algorithm checks composite grades whenever one is created or modified to ensure there are no circular references (i.e., a composite grade that has to calculate its own value for another composite grade before it can calculate its own value).

When the instructor clicks on the title of a composite grade, the settings for that composite grade are displayed, along with summary statistics and the calculated grades for every student (Figure 39). To create a new composite grade, the instructor can click the appropriate link and go to a page with all the settings for the new composite grade (Figure 40). Sum and simple average grades give the instructor the option of dropping each students' lowest graded item before calculating the grade. Modifying an existing composite grade is also performed through this interface.

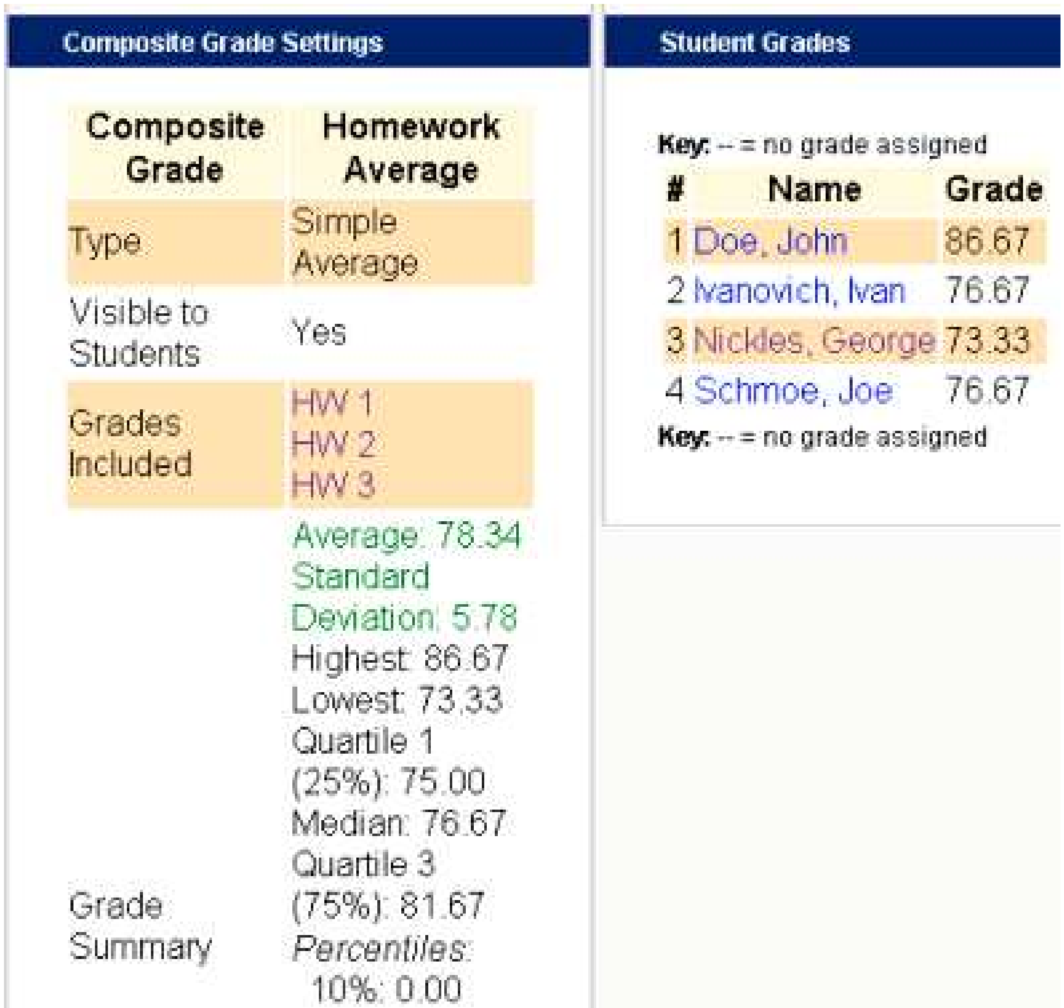


Figure 39: ITWeb Gradebook Component - Composite Grade View

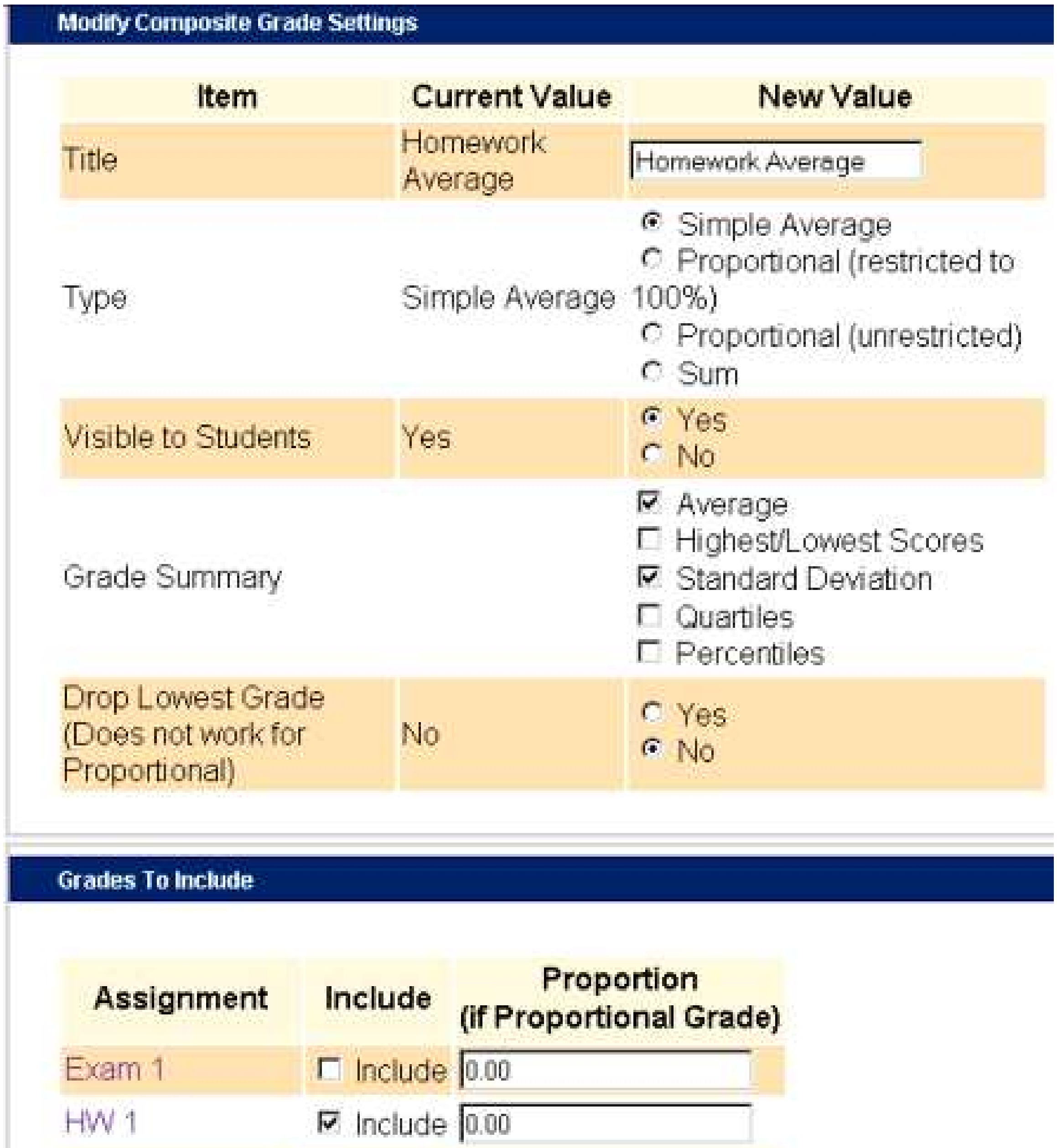


Figure 40: ITWeb Gradebook Component - Create and Modify Composite Grade

There are two other functions that instructors can perform in the gradebook: setting default options and exporting the grades. Assignment settings have defaults specified on the Defaults page (Figure 41). When set, the defaults apply to all new assignments created after that time and until the defaults are changed again. Second, the instructor may want to export all their grades in ITWeb to a file that can be read with spreadsheet software. The Export Grades page allows the instructor to download a file in comma delimited format (commas separate values) that follows the rows and columns format of the spreadsheet view in ITWeb. This type of file can be opened with most spreadsheet programs. It is not possible to import a data file to the gradebook at this time.

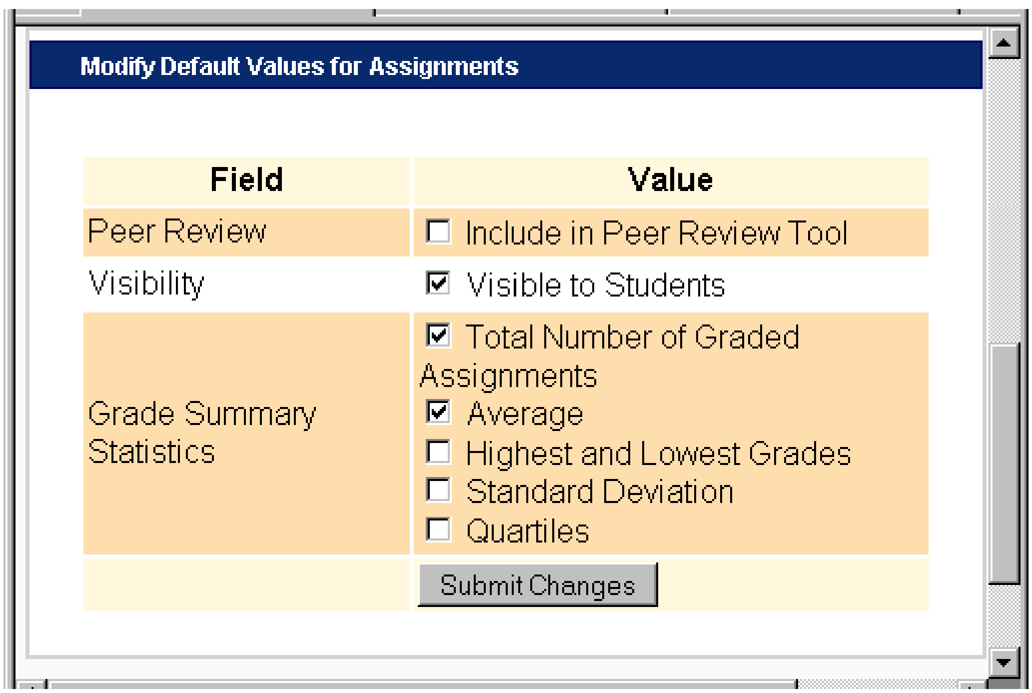
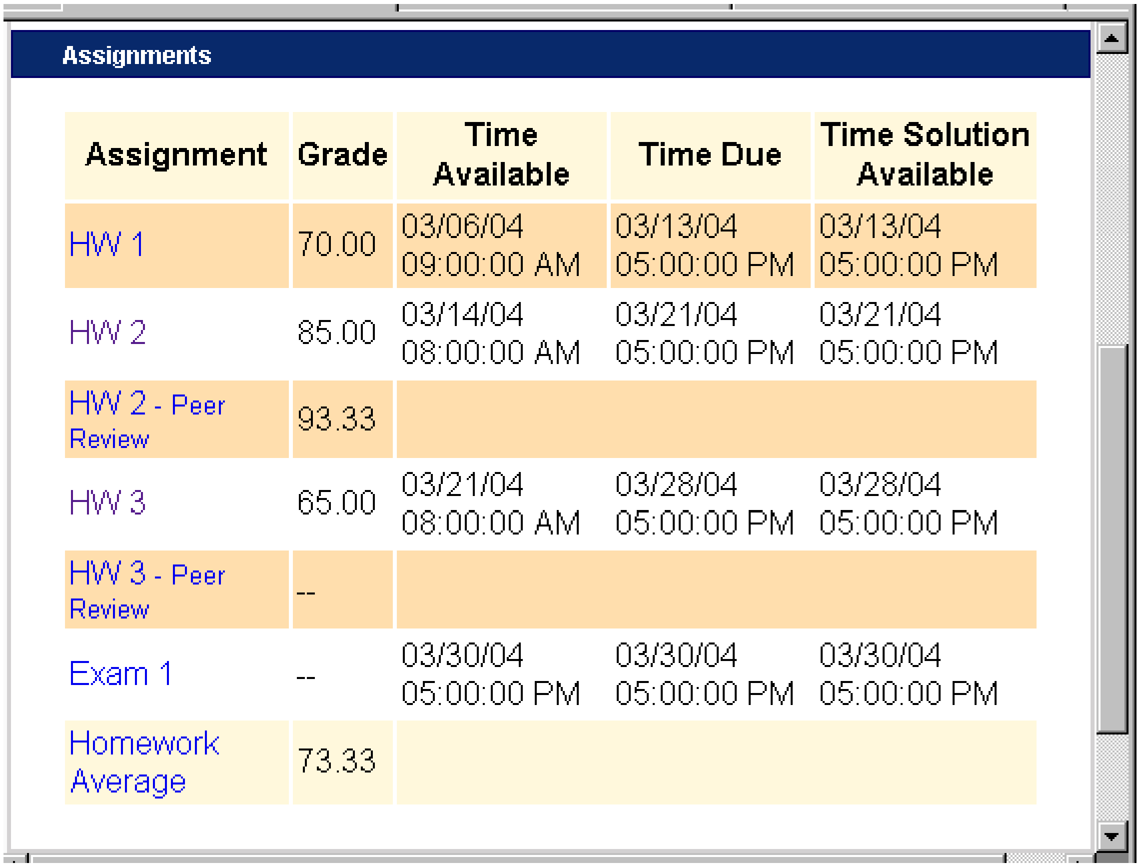


Figure 41: ITWeb Gradebook Component - Default Settings

Students have a separate display of the gradebook that limits the student to view only information related to that student. Students see an overview of the assignments, peer review grades, and composite grades in the course (Figure 42). Students can click on an assignment title and see information that is available according to the assignment release and due dates (Figure 43). If it is currently after the release date and before the due date, students upload their submissions for an assignment on this page and can leave comments for the instructor. If the due date has passed, the student can see the files submitted, their grade, any summary statistics available, and any feedback the instructor left. If the release date has not arrived, the student can only see that the assignment exists and the date it will be released. Peer review grades and composite grades can also be clicked to view details, but students cannot submit any files or information on these displays (see Figure 44 for peer review and Figure 45 for composite grades).



Assignments

Assignment	Grade	Time Available	Time Due	Time Solution Available
HW 1	70.00	03/06/04 09:00:00 AM	03/13/04 05:00:00 PM	03/13/04 05:00:00 PM
HW 2	85.00	03/14/04 08:00:00 AM	03/21/04 05:00:00 PM	03/21/04 05:00:00 PM
HW 2 - Peer Review	93.33			
HW 3	65.00	03/21/04 08:00:00 AM	03/28/04 05:00:00 PM	03/28/04 05:00:00 PM
HW 3 - Peer Review	--			
Exam 1	--	03/30/04 05:00:00 PM	03/30/04 05:00:00 PM	03/30/04 05:00:00 PM
Homework Average	73.33			

Figure 42: ITWeb Gradebook Component - Student Main View

HW 2	
Time Available	Sunday, March 14th, 2004 08:00:00 AM
Time Due	Sunday, March 21st, 2004 05:00:00 PM
Time Solution Released	Sunday, March 21st, 2004 05:00:00 PM
Late Submissions Allowed	No
View Assignment	homework02.doc
View Assignment Links	--
Instructor's Assignment Comments	
Topics Associated With This Assignment	**Procedures** Procedure Following Procedures and Roles of Humans Preflight Inspection Experiment
Student Comments	
View your submitted file(s)	hw2_nickles.doc
View your submitted link(s)	--
Last Update	Tuesday, April 20th, 2004 03:16:10 PM
Your Grade	**85.00**
Instructor Comments to You	
Grade Statistics	Total Assignments Graded: 4 Average: 85.00 Std. Dev.: 7.07
View Solution	--

Figure 43: ITWeb Gradebook Component - Student Assignment View

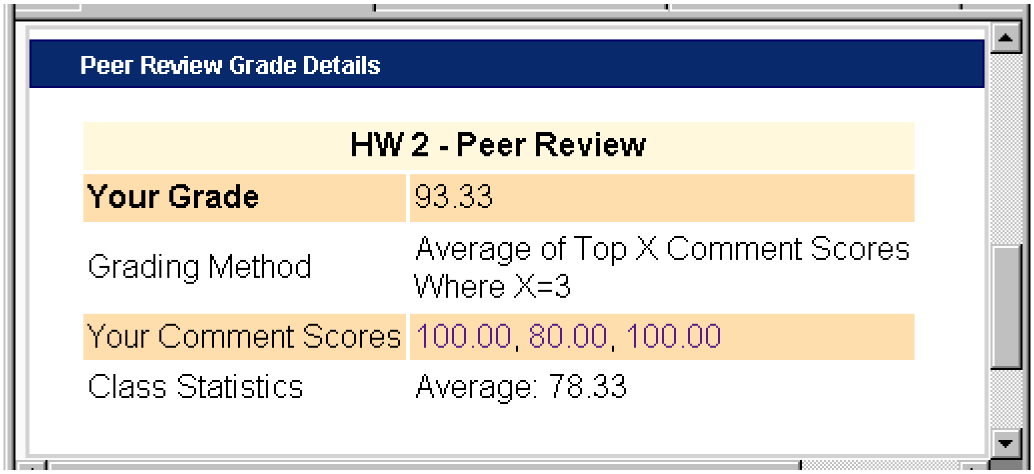


Figure 44: ITWeb Gradebook Component - Student Peer Review View

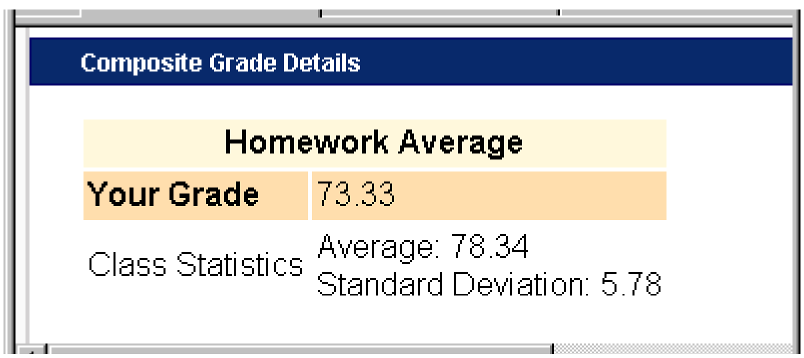


Figure 45: ITWeb Gradebook Component - Student Composite Grade View

4.3.3 Process Measures

As noted in chapter two, when some or all aspects of a course are administered through the Internet, student interaction with the CMS becomes a normal part of course activities. In courses that use a CMS, student interaction with the system can be recorded automatically and quantitatively for analysis. One source of information that is readily available is the web server log. Details are given in the following sub-sections on using a web server log to measure interaction with a CMS.

4.3.3.1 Contents of the Web Server Log

The World Wide Web is based on the concept of one device (a client) requesting information from another (a server). Web server logs are intended to monitor access to the files on the server. When a client device (e.g., a desktop computer) requests a web page, or any other type of electronic file, it sends a signal through the Internet requesting the server to send the data for that file. Every time a file is requested from the server, a one-line entry is added to the end of the log, typically called a "hit." One hit to a web page can result in several files being requested from the server, as the page may have images or script files it must also request to display properly. The large size of the server logs generally requires them to be analyzed automatically, and many software programs are available to analyze these for statistics such as how many times a single file has been accessed.

For the purpose of evaluating the use of a web-based CMS, there are three important items of data recorded with each hit in the log: the requesting Internet Protocol (IP) address, the date and time of the request, and the file name and directory path. The IP address is a unique identifier for each device currently connected to the Internet, which identifies the device, typically a personal computer, that requested the file. The date and time record when this request took place (to the second, according to the server's internal clock) and can be used to sequence the requests from a single IP address. The file name and directory path identify the file that was requested.

It should be noted that web servers can deliver any type of data, including web pages that are not related to a CMS. If the server log is to be used, the data must be filtered to only include the entries related to the CMS (Randolph et al., 2002). Also, individual students may use one of several computers in a lab or access the site from a dorm room. Thus, a single IP address cannot be directly associated with a single user. Although a student cannot be consistently matched to a single IP address, it can be reasonably assumed that a series of hits from one IP address very close to each other in time with large gaps of time (e.g., at least thirty to sixty minutes) separating these series from each other mean one user was accessing the website from that one computer for one series. One such session is referred to as a "visit" (Ingram, 1999-2000). If users are required to login to the system using an individual account, then all the hits and visits for the website can be exactly matched to individual users. In a record of an individual's login to the system, the IP address from which they request files from the server and the time of the login can be recorded. The time and IP address are then matched with the server log to determine exactly what students examined.

4.3.3.2 Web Server Log as a Process Measure

A process measure based on the web server log has the advantage of exhaustively capturing all the interactions with the web server, in contrast to process measures such as student time cards and written surveys about website use. This ability to objectively capture every interaction is a significant improvement over other methods of collecting process measures in that it does not rely on the vigilance of human observers or participants to record all actions, and it provides more details than can often be gained from time cards or surveys. Also, the authors' experiences and the literature (e.g., McNulty et al., 2000) have shown discrepancies between website use reported by students and interactions recorded in the server log. The server log may be considered the more objective of these two sources of process measures.

Another advantage of using the server log is that some behavior that cannot be collected practically in traditional instruction can be captured through the CMS. In courses that use a CMS, several measures can be collected, including what time and for how long students access course content (such as lecture notes). Measures of time will still be imperfect as students may shift to other tasks and then back to the CMS while still logged in or may download material and review it off-line. With a web server log some frequency measures can be collected, such as how often course content or feedback on assignments are accessed. Also, if students must submit their work to be graded through the CMS, the time it is submitted is recorded, identifying an upper bound on the time the work was completed. Similarly, if the student can retrieve grades and feedback on assignments through the CMS, those interactions are also recorded in the log.

A number of student behaviors while accessing educational sites can be quantified from the web server log (Ingram, 1999-2000; Rahkila & Karjalainen, 1999). First, the number of individual hits on a single web page or file can be determined. This gives some indication of how frequently students are viewing and reviewing resources available through the CMS, such as course content and feedback on assignments.

Though it does not absolutely capture whether each individual student has seen the available content (for example, students can acquire a copy of the content from other students) a problem can be indicated if there are very few or very many hits, especially for content that can only be accessed through the Internet. In addition, when the files with course content that are covered by each assignment are known in the system, the percentage of files hit for each assignment can be determined to estimate how much of the material students have covered. Some analysis can estimate the number of visits to the website and the amount of time spent during the visit, which can indicate how frequently students are interacting with the CMS for learning activities.

4.3.3.3 Inferences About Learning from Web Server Log Data

Since all process measures only capture physical actions, not the implied cognitive activity, the evaluator must make inferences as to what cognitive activity is taking place that drives the physical actions. The use of a CMS in education will result in particular types of interactions and cognitive activity that are distinct from interactions with other types of websites. One inference is the meaning of a hit on a file, which typically means that the user retrieved and viewed the file. Thus, a hit on a content file generally implies that the student has looked at its content at least once, although that may be at some time after downloading it. Additionally, if the content is only available through the CMS, it is assumed that the student has not seen the file before the first hit. This may not always be true as students may collectively organize and arrange for one person to download the file and print multiple copies. Another inference is that the vast majority of the duration of a visit to the website is time spent in course activities. Again, this may not be true as students may shift to other tasks during that time. While imperfect, these measures can be extracted from a server log and judged accordingly by an evaluator.

4.3.3.4 Quantifying Student Behavior from Web Server Logs

Web server log data must be examined in the context of how the technology is used, as discussed in chapter two. In one study, an educational website that teaches children to program collected a log of student interactions while programming (Bruckman et al., 2002). It was found that time on task in programming, as determined from the interaction log, is significantly correlated with programming performance. While this was not a web server log, it directly recorded the activity of students and accurately indicated the amount of time spent on task. Another study showed that university students who actively used an online study tool before exams had higher scores on the exams than those who did not use the tool (Grabe & Sigler, 2002). This was an interactive tool available only through the website, so the measure essentially captured the physical actions of students. A controlled study of student interaction with a Web-based learning module showed that time on task was a strong predictor of student learning (Taraban et al., 2001). In this study, students were only able to access certain information through the Web-based module and their use was timed by a login function.

While these studies show a relationship between student learning and data that can be gathered from logs, especially web server logs, all the learning tasks studied required that the physical actions be performed with the technology. This condition will not be true when a course website is only used to disseminate information to students. For example, if all the course content is available at the beginning of the semester on a course website, a student could download all the content on the first day of class and never visit the website again. Learning would take place as the student reads and reviews the notes off-line. This is a very different context for use of the technology and so the meaning of the data collected from web server logs must be changed accordingly. This is also seen in the literature. An exploratory study that examined various factors that could impact on-line learning found a strong correlation between the total number of hits on the course website from individual students and their average grade for the course (Comunale et al., 2001-2002). A regression analysis included total number of hits within the website as the main explanatory variable for the average grade for one course; however, individuals' GPA information was lacking for this course and was the major factor in a regression analysis of another course that was studied. In this case, the website appeared to be used for both activities requiring little interaction with the website, such as distributing content files, and for interactive learning activities such as a discussion board. Another study examined both data across the whole course and divided the data for the course into three time periods corresponding to the three exams (McNulty et al., 2000). When examining data for the Web Forum section of the website in aggregate, it was found that, among the 1/3 of the students with the highest grades, there was a positive correlation between number of visits to this section and final grade in the course, while no such correlation was found in the 1/3 of students with the lowest grades. However, when the average length of each visit made on the website during each of the three time periods was compared to grades on the corresponding exams, there was a strong negative correlation for the first exam and a moderate correlation for the second. This means that students with longer visits tended to have lower grades on the first two exams. This result may be explained by the nature of the website. The Web Forum section of the website is an interactive activity that can only be performed while on-line. Thus, server log data related to interaction with that module measures the amount of physical actions used in learning, and a positive correlation between physical actions of learning and performance should be expected. However, much of the rest of the website consists of content that can be downloaded and viewed off-line. In this case, students are not necessarily interacting with the content while logged on to the website, so the measure of average time per visit may not be meaningful in examining physical actions in this context.

4.3.3.5 Implementation of Web Server Log Measures

ITWeb is installed on a virtual server, which allows the web server software to create a server log that only includes files requested for ITWeb. This eliminates the need to filter out data not related to ITWeb.

Another feature of ITWeb is the login system, which forces users to identify themselves in order to use ITWeb. The login system distinguishes between the types of users (e.g., student and instructor), and allows access to the parts of ITWeb for which that individual user is authorized. When a user logs in to ITWeb, they provide a username and password (Figure 46). This combination is tested against the usernames and passwords stored in the database. If the login is successful, the user is forwarded to his or her ITWeb home page giving them several options and showing the courses for which they are currently registered (Figure 47). Also, using the sessions feature of PHP, global variables are created for this user's session containing the user's id number and user type. In addition, a new record is created in a database table recording the user's id number, the time they logged in, and their current IP address. While the user is logged in, the server software records every hit the user makes along with the time of the hit and the IP address of the hit. On almost every page in ITWeb, the user has the option to click on "Logout" to log them out of the system. If this link is clicked, the last record in the table of logins that matches the user's id number is updated with the logout time. Also, the session in PHP is closed, removing the ability to access the content for which the user has permission. If the user does not click logout but simply leaves the site and closes the browser, the session ends and the logout time in that record remains at its default value of zero. Thus, process measures can be assigned to individual users with a high confidence.

Figure 46: ITWeb Login Box

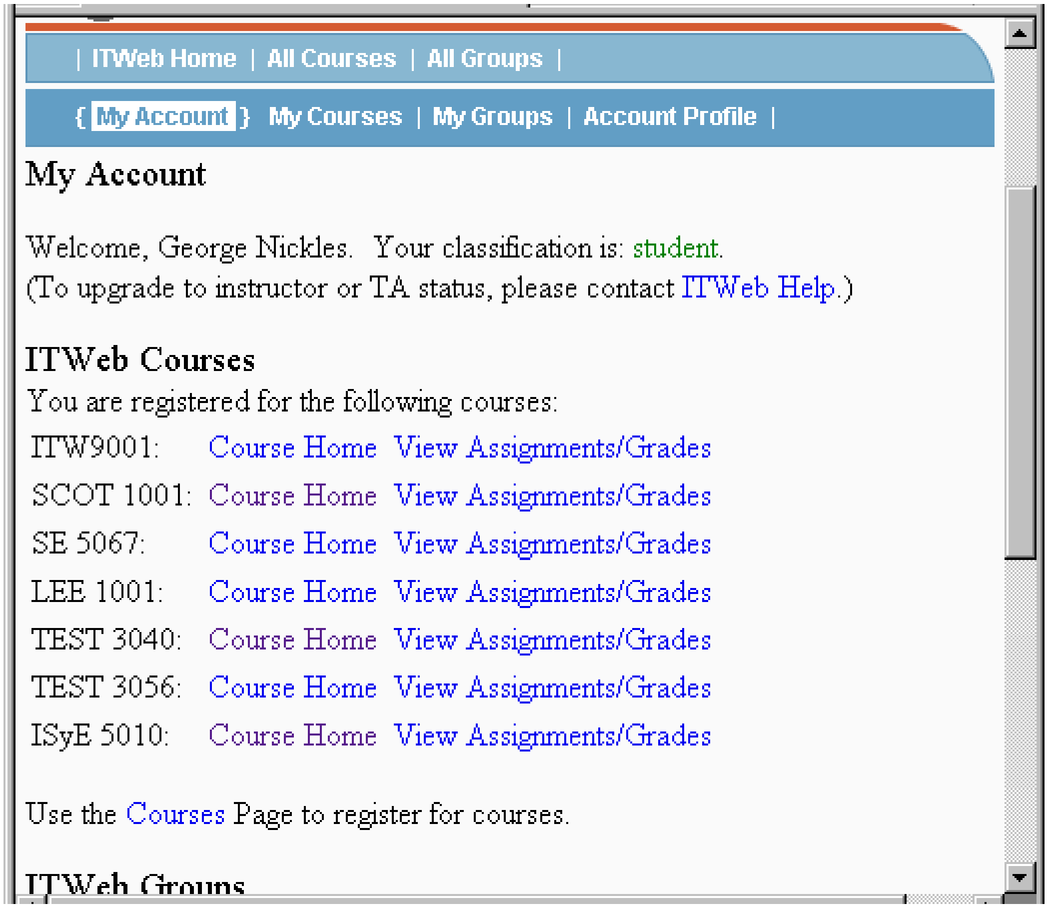


Figure 47: ITWeb User Homepage

To generate the evaluation data, a perl script was written for ITWeb to match hits with a single user and then calculate statistics on the content files for evaluation. This perl script is set to run every night at 3:00 a.m. so that it does not interfere with most other tasks of the server. This perl script performs three major tasks: 1) store all entries in the server log file that are new since the last update as records in the database, 2) determine logout times for users that did not click on the logout link, and 3) pair hits from the log file with students who are registered for the course to generate statistics on the content files.

There is no upper bound to the size of the server log file beyond the limitations of the server's file system and hardware. As there can be many hits to a web site just in a single day, the files can be quite large. Also, it may be the policy of the server administrator to occasionally back up and delete the current log file so that it starts over with no entries. To prevent loss of data and reduce processing time required to search through the log file, the perl script in ITWeb creates a record in a database table with the information on each hit recorded in the server log file. A single record includes the file hit, the time of the hit, and the IP address of the request. Thus, from here on, any examination of the data from the log file can be performed through queries of the database rather than searching through a set of large log files.

Next, it is necessary to determine all the logout times for each user. This allows estimation of the length of visits for each session, and assists in matching hits to users. The perl script queries the database for login records where the login time is greater (later) than the logout time, meaning the logout time is either in error or is zero. For each record meeting this criterion, the perl script searches for any login records where the same user logged in or any user logged in from the same IP address later than the login time of the current record. If such a record is found, then the logout time of the current record must be before the login time of the next record meeting the criteria. The logout time is then estimated as the time of the last hit before the new login from this user or IP address. If there are no hits before the next login, then the logout time is set equal to the login time.

If there are no recorded logins after the current login, then the logout time is estimated from the last hit before a session timeout. A session timeout occurs when the client requests no files for a designated period of time, which on the ITWeb server is set at three hours. After this period of inactivity, the server closes the session and the user must login again to access ITWeb content. When attempting to determine logout times, it is necessary to calculate if the last hit was made between the time the perl script is running and that time minus the session timeout. If this happens, the user may still be logged in and working in ITWeb, and the last recorded hit may not be the true last hit of the user's visit. In this case the logout time is not changed so that it can be updated the following day when more data is available.

It should be noted that the logout times determined by the perl script are estimates of the logout time, not the actual logout time. A user could conceivably examine a web page for the entire session timeout period and beyond, and the logout time would be estimated by the time of the last hit. As it is not possible to determine how long the user looked at the last page hit (or any page), this is only a means of estimating the timing of the user's visit.

The third major task of the perl script is to calculate the statistics on each content file associated with a topic. For each content file, several statistics are calculated:

- total hits made by students registered for the course,
- hits per registered student (total hits made by registered students divided by the number of registered students),
- hits in the past 30 days per registered student (total hits made by registered students in the past 30 days divided by the number of registered students),
- hits in the past 7 days per registered student (total hits made by registered students in the past 7 days divided by the number of registered students),
- hits within one day of topic coverage per registered student (total hits made by registered students between one day before and one day after the topic coverage date, divided by the number of registered students),
- hits within three days of topic coverage per registered student (total hits made by registered students between three days before and three days after the topic coverage date, divided by the number of registered students),
- hits within five days of topic coverage per registered student (total hits made by registered students between five days before and five days after the topic coverage date, divided by the number of registered students), and
- total number of hits by all ITWeb users (including students registered for the course, and any user not registered).

To calculate these values, the perl script queries the database for all the content files in the system. Each file is processed through the following algorithm. First, the script determines if there is a database record of statistics for this file, and if not, creates it. Next, the database table with the entries from the server log file is queried for all entries that match the current content file that are made by registered students. This is done in a single SQL query that joins the course roster table (to determine who is in the course), the logins table (to determine when those students logged in and out), and the table of log file entries (to identify the hits made by registered students). Only the date and time are retrieved for each record on this query. Each record retrieved is examined to determine if they are within the past seven or thirty days, and if they are within one, three, or five days of the topic coverage date. These are to give the evaluator the pattern of student accesses to the material with respect to the topic coverage date. The evaluator can infer whether students are preparing for the lecture by downloading the content and if they tend to review the content after the lecture. Also, showing evaluators if students have reviewed the content on-line in the past seven or 30 days can indicate if a review of this older material is needed when building on it for new material. In addition, if students had difficulty with the material, this can show if students are reviewing that material over time. Counters are incremented as appropriate. A separate query is performed to determine the total number of hits made on this file by all users. When all these values are found, they are updated in the current file's record of statistics. Note that the values stored here are the totals, not the per student values. A series of queries could be performed to determine these values, but the amount of time to perform a single query on these large database tables (especially the server log entries table) is sufficiently large that the perl script using only one query is faster.

At this time, all values for all files are recalculated every time the script executes. Over time, as more content files have been added and the server log has become much larger, the time required to execute the script has grown beyond that desired by the web server administrators. Several efficiencies can be made to this algorithm, including only adding to the total hits since the last update and not re-calculating the number of hits within a few days of the coverage date if the coverage date is old enough for there to be no new hits in that range. Also, the database table containing the entries from the server log file is very large. Separate tables could be created for different semesters or months of data, reducing the load on the SQL queries in the script. This would require special handling of the queries, but it is possible to reduce the load in this manner and retain all previous data if it is needed for further research purposes.

At any time, the evaluator can go to the server log report for a topic and view the statistics for each file related to the topic (Figure 48). A topic can have multiple files associated with it, requiring statistics to be generated for each file. The statistics listed above are displayed for each file. In addition, baseline values are generated for all content files in ITWeb. This is the main reason for providing the values per student, so that each statistic can be compared with other courses or the average for all content files in ITWeb. This gives the evaluator some context for how often students are examining the content for this course in relation to how students examine content for other courses. As these statistics are calculated only once per day at approximately 3 a.m., this is not real time data, but it is up to date as of the time the script runs. Like the other measures, all the statistics are presented anonymously to the evaluator.

Topic: Human Error and Design

Log File Analysis

HumanErrorAndDesign.ppt

Measure	Value	Baseline
Hits (by registered students)/Students	1.3	1.1 (avg. all IT Web)
Hits in Last 30 Days/Students	1.3	0.1 (avg. all IT Web)
Hits in Last 7 Days/Students	0.3	0.0 (avg. all IT Web)
Hits Within ±1 Day of Topic Coverage/Students	0.3	0.0 (avg. all IT Web)
Hits Within ±3 Days of Topic Coverage/Students	0.3	0.0 (avg. all IT Web)
Hits Within ±5 Days of Topic Coverage/Students	0.3	0.1 (avg. all IT Web)
Total Hits (all users)	7.0	12.3 (avg. all IT Web)
Hits (registered students)	5.0	10.5 (avg. all IT Web)

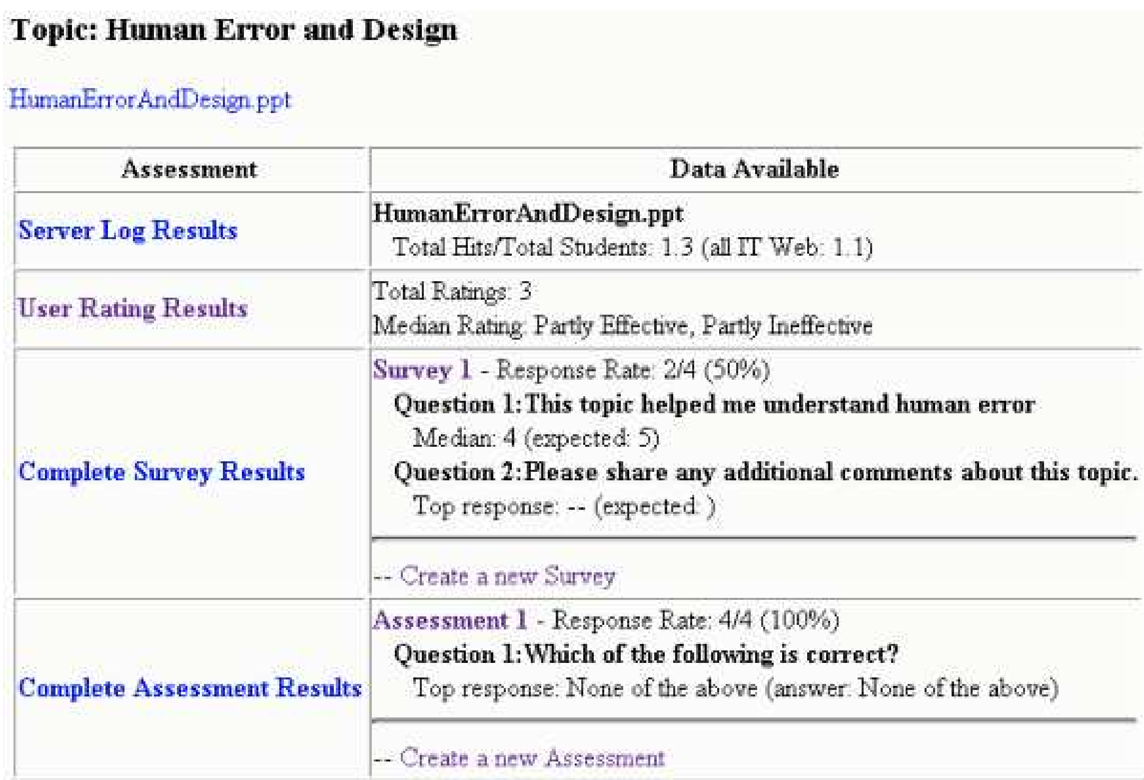
This Topic's Files:

HumanErrorAndDesign.ppt

Figure 48: ITWeb Evaluation Component - Web Server Log Analysis Results

4.3.4 ITWeb Centralized Evaluation Component

As seen in the preceding sections, the main evaluation component allows the evaluator to access the measures collected for each topic in the course. After selecting a topic, the evaluation system displays a summary of the measures that have been collected so far (Figure 49). These give the evaluator an overview of the measures all at once to allow a general judgment to be made about the effectiveness of this topic using the evaluator's mental model of the course. The additional details can be accessed as noted above, and links to create additional surveys and assessments are available here as well.



Topic: Human Error and Design

HumanErrorAndDesign.ppt

Assessment	Data Available
Server Log Results	**HumanErrorAndDesign.ppt** Total Hits/Total Students: 1.3 (all IT Web: 1.1)
User Rating Results	Total Ratings: 3 Median Rating: Partly Effective, Partly Ineffective
Complete Survey Results	Survey 1 - Response Rate: 2/4 (50%) **Question 1: This topic helped me understand human error** Median: 4 (expected: 5) **Question 2: Please share any additional comments about this topic.** Top response: -- (expected:) -- Create a new Survey
Complete Assessment Results	Assessment 1 - Response Rate: 4/4 (100%) **Question 1: Which of the following is correct?** Top response: None of the above (answer: None of the above) -- Create a new Assessment

Figure 49: ITWeb Evaluation Component - Topic Results Summary

In this form, ITWeb's centralized evaluation component provides all the available evaluation measures in one interface for judgments about each topic. However, the evaluator still needs to interpret the measures using a system model, whether an internal mental model or an explicit system model.

4.4 Summary

This chapter shows how this dissertation has met its third objective "develop a set of measures for formative evaluation that can be administered through a CMS with built-in data collection and analysis capabilities." Educational measures from each of the three types identified in section 2.2.5 (performance, perception, and process) can be implemented in a CMS. In this case, ITWeb has implemented surveys, student ratings, assessments, and a server log analysis in a single evaluation component as described in section 4.3. The tools are readily available to evaluators, the measures are administered on-line automatically to students, and the summary results are generated by the software. Not only do these measures reduce the time and resources required to administer measures, they are collected in one interface, facilitating their use for formative evaluation along with a system model. In addition, the process measures provide a level of detail that is not normally feasible to collect.

CHAPTER 5

APPLICATION OF WORK ACTION ANALYSIS FOR PLANNING AND FORMATIVE EVALUATION

The previous chapters have developed the elements needed for planning and formative evaluation of an undergraduate course: a model for an education system based on WAA, WAA’s method for developing and applying this model, and measures collected through a CMS. Just as the application of work domain analysis to process control guides system design and ecological interfaces, WAA is applied here to bring greater insight to the evaluation of education. To demonstrate the use of WAA and CMS measures for planning and formative evaluation, they are applied here for those purposes to a portion of an undergraduate engineering course. While this analysis is intended to be a demonstration of planning and formative evaluation, the analysis actually took place after the course had ended. Even so, the analysis was performed as if it were taking place before and during the course. The measures for formative evaluation were collected through the CMS, ITWeb, during the course.

5.1 Work Action Analysis as Planning Evaluation

Planning evaluation is typically performed during the design phase of a learning service system and provides designers "with an understanding of what the project is supposed to do and the timelines and strategies for doing it" (Stevens et al., 1993, p. 4). If the design of the project is not clear or elements of the system do not align with the system goals, then the design must be refined.

As described in chapter three, the method of WAA first involves determining the scope and purpose of the analysis. The scope is defined according to what exactly will be evaluated, e.g., a specific portion of a course.

Second, the modeler must determine the overall goals of the system. This step identifies the goals to which the system must be aligned. Many methods that describe a planning evaluation state that one of the first tasks of such a process is to identify the objectives of the educational system (Grady, 2002; McGourty et al., 2002; McGourty, Sebastian, & Swart, 1998; Walker, 1997; Stevens et al., 1993). (It should be noted that some of the references above include both planning and formative evaluation activities; the discussion here only refers to those aspects that are pertinent to planning evaluation.)

Next in the method described in chapter three, the modeler must then determine the levels of abstraction, parts-whole decomposition, and roles that define the framework in which to model the system. The modeler can either use the framework for a course described in chapter three or derive a similar one that is more appropriate for the system being evaluated.

In the next two steps of creating a WAA model, the modeler must populate the framework with the system elements and their relations. The methods for planning evaluation referenced above differ on the next steps to take in planning evaluation, thus the method described by Grady (2002) will be discussed as it is the most clear and detailed. The second step in Grady's method is to identify the instructional strategies, which includes the cognitive activities and physical actions (though those terms are not used) of the instructor and students, the content to be taught (a part of atomic elements), and the delivery mechanism (another atomic element). Stevens et al also mention the need for examining strategies and interventions in the planning evaluation stage (Stevens et al., 1993). Identifying these system elements is equivalent to populating the WAA framework. In fact, WAA is more specific than the method used by Grady (and others) in that rather than simply labeling system elements as "content" or "strategies," they are placed specifically within the three dimensional model using a structured method that builds in from the elements that are the easiest to identify (goals and atomic elements in the ‘corners’ of the model). The method of creating a WAA model is also more specific with respect to each role in the system. In WAA, the modeler must identify the objectives of each role and the atomic elements at the lowest parts-whole level, then populate the framework with elements between these. The WAA method also allows the modeler to specify objectives for the sub-parts of the system along the parts-whole dimension. For example, an instructor may have objectives for assignments early in the course that serve as intermediaries for achieving the ultimate course objectives; students must acquire knowledge of basic principles before they can apply them. In this sense, WAA is superior to other forms of planning evaluation in that it allows for objectives of sub-parts as well as the overall system. Also, while the above referenced methods of planning evaluation speak of identifying elements, WAA additionally identifies the relations between the elements.

The third step in Grady's method is to identify how learning will be assessed. Others include this step as a key element of planning evaluation (McGourty et al., 1998; Walker, 1997). If the WAA framework developed for a course in chapter three is used, the assignments are integrated into this framework as a category on the parts-whole dimension. The WAA framework is superior to the more generally stated methods in that it incorporates assignments into the modeling framework according to their place in the learning system structure rather than treating them as isolated components.

Planning evaluation can go beyond identifying the system elements, including goals, to include examining the alignment of these elements. As discussed in chapter two, examining alignment involves taking a systems approach to education, specifically, determining if the system goals should be met by the other system elements. However, in spite of the discussion of alignment in Bransford et al (2000) and others noting the need for alignment (Grady, 2002), though in different terms, these studies do not specify how to determine if a system is "aligned." Determining if a system element will support the achievement of a goal involves examining the relation between them. The desired relation is one where the system element is a means to accomplishing the end of the goal. Thus, if a means-end relation (or a chain of means-end relations) exists between a system element and a goal, then the element and goal are aligned. Thus, determining during planning evaluation if system goals and elements are aligned essentially involves determining if means-end relations exist connecting all the system elements to the objectives. These means-end relations may span the roles in the system via relations between roles; for example, students' cognitive activities may be enabled or required by atomic elements created for them by the instructor. In this, WAA makes a critical part of planning evaluation explicit, so that the relations between elements can be determined through the WAA framework. Dorneich's (2002) work is very similar to this use of WAA in that the means-end relations in the abstraction hierarchy are used to determine if the objectives and other system elements are connected.

In summary, the method of creating a WAA model can be used for planning evaluation. This method identifies the system goals, role objectives, instructional strategies, and assessment methods. In addition, WAA provides a way to represent explicitly the means-end relations between system elements that are necessary to determine how well the system elements are aligned with the system goals.

5.2 Planning evaluation of a Course with Work Action Analysis

To demonstrate WAA as a planning evaluation method and to determine how effectively this method provides deep insights to an educational system, it has been applied to a portion of an undergraduate course using the method described in Chapter 3.

5.2.1 Course to be Evaluated

The course used in this evaluation is ISyE 4009 taught in Spring, 2003 at Georgia Tech. Of the 53 students in the class, 49 (92%) gave consent for their data to be used for research purposes. The course instructor presented lectures using PowerPoint presentations that were made available to students through ITWeb as topics. The teaching assistant graded all the homework assignments, except the first, and peer comments for the course, while the instructor graded all the projects. The teaching assistant and instructor graded the exams together.

The first exam covered the course material also covered by homework assignments one through five and the first three parts of the course project, representing approximately one third of the course material. Only the portion of the system encompassed by the first five homework assignments will be examined. This portion of the course was chosen for study in part to reduce the scope of the analysis for this demonstration. Also, this portion of the course is, in a sense, a mini-course with a cohesive set of content covered by assignments and a comprehensive exam. Course content has been divided into individual topics, which, for the sake of space, will be referenced to by their topic number in ITWeb (see Table 6).

Table 6: Topic Numbers Matched to Their Content for ISyE 4009 from Spring, 2003

Assignment Covering This Topic	Topic Number	Topic Name
1	390	Introduction to Human Integrated Systems
2, 3	406	Gathering Customer Data
2, 3	407	Principles of Contextual Inquiry
2, 3	408	Some Foci of Contextual Inquiry
2, 3	410	Models to help in Contextual Inquiry
3	433	Modeling Work – Overview
3	434	Artifact Models
3	435	Cultural Models
3	436	Flow Models
3	437	Physical Models
3	438	Sequence Models
4	439	Procedures and Proceduralization
4	440	Procedure Following
4	441	Procedures and the Roles of Humans
4	442	Example: Study of Procedure Following
5	447	Decision Making Overview
5	448	Strategic and Tactical Decision Making
5	449	Supporting Strategic/Tactical D. M.
5	450	Opportunistic Decision Making
5	451	Examples of Opportunistic D. M.
5	452	Supporting Opportunistic Decision Making
5	453	Example: Study of Opportunistic D. M.

The first homework served as an introduction to the course, requiring students to find job advertisements describing the knowledge and skill set needed to work in the domain covered by this course. The other homework assignments were very similar in format: students were to identify a good design and a bad design and describe why they are good or bad in light of the current course content.

5.2.2 Making the Work Action Analysis Models

The method for creating a WAA model described in chapter three was used to model the portion of the course covered by the first five homework assignments. The following is a description of how the method was followed. The final representations of the system resulting from this method are in Appendix A. To identify the separate roles, this section will refer to the evaluator as the person performing the planning and formative evaluations and to the instructor as the person designing and teaching the class, though in practice these may be the same person. For this evaluation, the role of the evaluator is not considered as it is not part of the actual execution of the course. The analysis was actually performed by the evaluator with support from the course instructor. Also, this section is presented as though it is a linear method, but in practice it will be iterative.

5.2.2.1 Determine the Scope and Purpose of the Analysis

The scope of this analysis is a portion of the course ISyE 4009 taught in Spring, 2003. Specifically, the scope includes the system elements in this course that are associated with the first five homework assignments. The purpose of this analysis is planning and formative evaluation of this portion of the course.

5.2.2.2 Determine System Goals

The goals of the system are identified as the course objectives. The course syllabus was available at the time of this analysis and stated six objectives for the course:

- understand how we, as engineers, can design information systems to create effective work processes,
- learn how to identify and design for the needs of workers and organizations,
- create machine interface designs that establish and support good work practices,
- be able to identify and communicate the properties of a machine's interface,
- understand the limitations of human operators under a variety of situations, and
- understand the principles of human-integrated systems evaluation - and apply them to your project design.

5.2.2.3 Identify All the Roles of Agents That Are Integral to the System

The two roles of agents that are primarily involved in the operation of the system described above are the roles of instructor and student. While there is a teaching assistant assigned to this course, her functions were to assist on a subset of the instructor’s duties. Thus, all system elements of the teaching assistant can be modeled here as part of the instructor’s role. In other cases, it may be necessary to separate these two roles.

5.2.2.4 Identify the Levels of the Parts-Whole and Means-End Dimensions

In this step, the evaluator specifies the framework in which to represent his or her mental model of the system. This system is a portion of a course, and a WAA framework for a typical undergraduate course was developed in chapter three (see Figure 13). This framework has a column for the course at the highest level of the parts-whole dimension, then columns for each assignment at the next lowest-level, and finally columns for each topic at the lowest level. For the means-end dimension, rows represent, from highest to lowest, goals, cognitive activities, physical actions, and atomic elements. Each assignment must necessarily be given in a temporal sequence in the course, which can reflected by the order in which their columns are shown in the model. This allows the evaluator to see how learning can build over time from early and intermediate levels of cognition (e.g., knowledge, comprehension) to higher ones (e.g., application, synthesis). The framework that will be used for each assignment is shown in Figure 13.

5.2.2.5 Fill in the Items at the Lowest and Highest Levels on the Means-End and Parts-Whole Dimensions

At this stage, the evaluator must identify the objectives of the roles at the course level (the top-left of the model as it is drawn) and the atomic elements at the smallest parts-whole level (the bottom-right of the model). Each role has its own set of objectives for the course which need to be identified. For the student role, a typical objective is to achieve the desired grade in the course, which drives student behavior in completing graded assignments. Students may have other course wide objectives such as personal interest in the subject of the course, a general joy of learning, or a desire to prepare for a particular career. The role of the instructor also has objectives on the scale of the course. One set of objectives of the instructor is the course objectives. These may be defined by the instructor or a course designer and are one set of objectives that guide the behavior of this role. The instructor may have objectives besides the course objectives such as improving students' communications skills and assessing each student's proficiency in the course. This illustrates that both roles are part of the same system (i.e., the course) but need not have any objectives in common.

The atomic elements at the smallest parts-whole level must be identified in the bottom right of the model. The list must be detailed and complete and includes all PowerPoint presentations used during lecture, all notes taken by students in class, all lecturing notes by the instructor, the lectures themselves, communication between instructor and students outside of class, and any other atomic elements that may apply.

Figure 50 shows the beginnings of filling in the model with these elements for the role of the instructor. Only atomic elements related to the first topic are shown in this example. The complete versions corresponding to each of the homework assignments can be found in Appendix B.

Role: Instructor			
	Course	Assignment	Topics
Role Objectives	Course objectives, assess student learning		
Cognitive Activities			
Physical Actions			
Atomic Elements			Introduction.ppt, lecture, instructor notes, out-of-class discussion

Figure 50: Intermediate step in WAA for the role of the instructor showing only the first topic

5.2.2.6 Fill in the Items at All Other Levels, Identifying Relations Between Levels

This step consists of two major activities that are performed iteratively until the evaluator is satisfied that the end result is an accurate representation of his or her mental model of the course. First, the evaluator populates the table with the rest of the elements in the system, often working in from the upper-left and lower-right corners of the model populated in the previous step. Second, the evaluator identifies agent-environment means-end and parts-whole relations that exist between the elements. During this step, all other aspects of the model can still be changed as the evaluator sees more of the system represented in the WAA framework.

For the instructor's role, it is necessary to determine which of the course objectives each assignment is intended to support. Homework assignments one through five are available for this analysis, and each is matched with each set of course objectives they are designed to support. From this point, the discussion will focus on the first homework assignment and walk through its development.

The first homework assignment is to search professional job listings for positions involving the subject matter of ISyE 4009 and record the skills that are required for such a position. The purpose of this assignment is to give students a sense of the skills required in industry, and to see how those match with what is taught in the course. This activity is judged to support the course objective "understand how we, as engineers, can design information systems to create effective work processes" because it guides the students to consider the design skills they must acquire.

For the instructor's role in the first homework assignment, the immediate objectives of the assignment, "get students to relate course content to career" and "get students to work toward course objective 1," are placed in the role objective row and assignment column. Also, the document containing the instructions for this assignment is placed in the atomic elements row and the assignments column. The questions posed to identify means-end relations between elements at different levels of abstraction are useful for identifying other elements. To identify elements at the level of physical action in the assignment column, the evaluator identifies the immediate purpose at the physical action level. For the assignment file, the immediate purposes for the instructor include comparing the assignment and topic files to determine if they are congruous, writing the assignment, and posting the assignment in ITWeb. All these have means-end relations to the assignment file. Posting the assignment requires an ITWeb assignment record, which is an atomic element. Also in preparing the assignment, the instructor may examine previous assignments that are similar, adding previous assignments to the atomic elements with a means-end link to the physical action of examining previous assignments. The instructor also interacts with student submissions, which are atomic elements. Student submissions have a means-end relation with the physical actions of "read student submissions", "assign grade and leave feedback", and "compile the results." These physical actions also require the atomic elements of grades and "feedback on submissions." An additional physical action that is an end of the student submissions is discussing the submissions in class as feedback to the students. A final physical action of the instructor is to assign a weight to the grade on this assignment with respect to the overall grade for the course, which has a means-end relation to the syllabus where this is recorded. This action is part of the system related to this assignment, though it may take place long before the assignment is given to students. The syllabus is an atomic element in the course column as it applies to the entire system of the course.

Though not observable, cognitive activities bridge the means-end gap between physical actions and role objectives in learning service systems. Both the instructor and the student engage in cognitive activities to achieve the ends of the role objectives, and the physical actions serve as means to achieve the cognitive activities. The cognitive activities of the instructor identified with this assignment include “considering the past use of this assignment,” which has means-end links down to “examine the past assignment” and up to both assignment objectives. Another cognitive activity identified for the instructor’s role is “establish wording of the assignment.” This activity has means-end links up to both assignment objectives and down to the physical actions “create assignment in ITWeb,” “write assignment,” “examine past assignments,” “compare assignment and topics,” and “post files in ITWeb.” The complete set of system elements identified for the instructor’s role as a result of this step in the method can be found in Appendix B.

The role of the student may have several course-wide objectives related to this assignment. One typical objective for students is to achieve their desired grade level in the course, so this is included in the student framework. Also, students may desire to learn for the joy of learning or may be explicitly pursuing the knowledge and skills they perceive they need for their careers. In addition, students may desire to manage their time so they allocate their desired amount of time to this assignment.

In addition, students’ system elements at the atomic elements level on the means-end decomposition and the content level of the parts-whole dimensions for this assignment can now be identified. Elements at this level include any material, physical or electronic, that contains information on the content to be taught or communications of information between the agents. For homework assignments one through five, the content associated with each assignment comprises a set of PowerPoint files that are used during lecture and are available to students through ITWeb. The electronic topic records in ITWeb are also atomic elements as they give some information on the topics such as when they will be covered in class and are part of the organization of the course in ITWeb. The information communicated in the lecture is an atomic element since it is a communication between the two roles. Other communications between the roles include in-class discussions and out of class student-instructor dialog. In addition to these elements that are shared by both roles, students may take notes during the lectures to aid in study later, and instructors may have lecture notes besides the PowerPoint files. Atomic elements in the assignment column for the student include the homework assignment file, job advertisements, the student's submission, the grade and feedback on the submission, the ITWeb assignment record, and the feedback given to the whole class. These atomic elements are means to several ends at the physical action level. The physical actions of "acquire the homework file" and "read the assignment" are the ends of the homework assignment file. The student is then expected to engage in the physical action "checking topic files for keywords," which has means-end relations to the assignment file and the topic files. The physical action of searching for job ads is the end of the atomic elements of the assignment file and the job ads. The physical actions "compile relevant job ads" and "submit selected ads" are the ends of the atomic elements of the assignment file, the job ads, and the student's submission. "Read the grade and feedback on the assignment" is a physical action with means-end links to the grade and feedback, the submitted ads, the assignment, and the ITWeb assignment record.

As in the instructor's role, cognitive activities are the means-end bridge between the physical actions and role objectives. Here, the modeler places the cognitive activities in which students are expected to engage. The cognitive activity "evaluate time and effort to spend on assignment" is the ends of all the physical actions as this activity will guide their execution and is the means to achieve the objective "achieve the desired grade on the assignment" in the assignment column. "Select ads with respect to the content" is another cognitive activity and is the end of all the physical actions except "read the feedback and grade on the assignment" and "attend the discussion of the assignment." The cognitive activities "consider all job skills designated in ads" and "consider own submission with respect to feedback" are related to all the physical actions, as each is required for this activity to take place. The latter three cognitive activities are means to achieve both role objectives in the assignment column, and are related via this element to the broader learning aspects of the course objectives. The complete set of system elements identified for the student's role as a result of this step in the method can be found in Appendix B.

WAA models were made of the first five homework assignments and are shown without relations between elements in Appendix B. The method used to model these assignments is the same as developed in chapter three and as demonstrated above. One feature of the system that became clear is that homework assignments two through five followed a very similar pattern. Since the basic format of these assignments was the same, only the content, assignment, and related course objectives had to be changed for each model. This is a demonstration of the use of templates in building WAA models as described in section 3.4.2. The model developed for homework assignment two serves as the template for assignments three through five.

5.2.2.7 Identify Correspondence Relations Between Roles and to System Goals

In this final step, the modeler identifies the correspondence relations at the level of atomic elements between the roles and between role objectives and system goals. The roles of instructor and student share multiple atomic elements at each parts-whole level in the first homework assignment. At the course level these include ITWeb, the classroom, and the course syllabus. At the assignments level the roles share atomic elements such as the assignment itself and the grade and feedback. At the course level, the two roles share atomic elements such as information communicated during the lecture and the topic file. Each of these elements is identified as having a correspondence relation between the roles, in many cases because the instructor purposefully created them for the students.

The second place where correspondence relations can exist is between role objectives and system goals. The system goals are the course objectives, as identified in step two. In this case, the instructor has his or her own objectives for the course which, for the course to be aligned, must include the course objectives.

5.2.3 Benefits of Work Action Analysis for Planning Evaluation

The evaluator can gain several benefits from using the WAA method in planning evaluation. First, the method supports creating a comprehensive and detailed representation of the system that is external to the evaluator. This provides a concrete model of the system that can be used to communicate a detailed, comprehensive design of the system to others. Through the method of making a comprehensive and detailed model, the modeler will identify parts of the system that could otherwise be overlooked.

Second, the method of creating a WAA model serves to inform the evaluator's mental model, which may not be comprehensive, detailed, or accurate. By making the evaluator examine his or her mental model, areas of inconsistency may be revealed that must be resolved. Also, the method for creating a WAA model leads the modeler to consider a comprehensive view of the system across the three dimensions of the framework. Through this, the modeler may think in a more detailed and comprehensive way about the system, changing his or her mental model in those ways.

Third, WAA provides a structured method for planning evaluation, as presented generally in section 3.4 and as followed above in section 5.2.2. This method leads the evaluator through a logical progression of steps to build up a model, streamlining the method of creating a WAA model. Whereas other methods describing planning evaluation tend to be fairly general as discussed in section 5.1, the method described here provides specific guidance and examples to create a WAA model. Each step provides a foundation and guidance for the subsequent steps.

Fourth, the method of creating a WAA model can be used to explicitly test the alignment of the system. As noted in section 5.1, there is little guidance in the literature on specifically how to test the alignment of a system. Using the WAA method, an evaluator can determine if a system element is ultimately related to the system goals, or if it is not related to the goals via means-end and correspondence relations. WAA recognizes that not all roles explicitly attempt to achieve the system goals, but that they may be influenced by other roles so that the goals will be met. The system is aligned when all elements are related by means-end relations to role objectives and when roles that explicitly attempt to achieve the system goals influence other roles to that end via correspondence relations.

Fifth, the evaluator has a complete chain of means-end and parts-whole relations that show how any single element is related to the course objectives. This allows the evaluator to speculate how a failure at one element of the system would lead to a break in the sequence of elements that support a course objective. Also, the evaluator can determine how much redundancy is in the system by examining how many independent means-end chains lead to the goals, where a greater number of independent chains increases the likelihood that the goal will be met. An added benefit to the means-end relations is the ability to examine the path for an individual element to achieving the system goals in great detail. This allows the evaluator to determine not only if an individual element is a means to achieve the system goals, but also how direct the linkages are.

Sixth, this representation makes the cognitive activities explicit. By making these explicit, the evaluator can evaluate the atomic elements and physical actions not just in terms of each other, but whether or not they will support the cognitive activities. Cognitive activities are where learning takes place, and they are the immediate means to achieve the objectives of each role, thus emphasizing their importance in the system.

5.3 Work Action Analysis as Formative Evaluation

Formative evaluation, as discussed in section 2.2.3, takes place during the operation of a system for the purpose of finding ways to improve it. Summative evaluation, also as discussed in section 2.2.3, is performed once a life cycle of the system is over and is intended to determine the effectiveness of the system. There are many methods in the literature that can be applied to both formative and summative evaluation of education as the data is collected while the system is in operation. Gay and Airasian (2000), Walker (1997), and Stevens et al (1993) all provide evaluation methods that include planning the evaluation, collecting the data, and analysis, steps that can apply to either formative or summative. As an objective of this dissertation is to apply WAA to formative evaluation, WAA will be compared to these methods. The use of WAA for formative evaluation will be examined in relation to Walker's method as it is the most comprehensive of these methods. It should be noted that Walker's evaluation method (like the other two noted above) focuses on the evaluation of an intervention to a current system. Walker notes this by referring to a "project" or "intervention" as the item of interest in an evaluation study. Gay and Airasian and Stevens et al also speak of the purpose for their handbook as focusing on interventions:

> "The Handbook discusses quantitative and qualitative evaluation methods, but the emphasis is on quantitative techniques for conducting outcome evaluations, those designed to assess the results of NSF funded innovations and interventions" (1993, p. ix).

In contrast, the purpose of the WAA method of evaluation is to examine the system as it actually exists, rather than directly model the effect of individual interventions (as discussed in section 3.2.3). Thus, the utility of WAA in implementing interventions comes from its ability to represent what is currently happening within the system (thus enabling the evaluator to better identify where interventions are needed) and, if the interventions are then represented in the model, to evaluate them in the context of a comprehensive, detailed model of the system.

The first step of Walker's method is to define the purpose of the evaluation. This is also the first step of developing a WAA model in planning evaluation, the first step in the comprehensive method of using WAA for planning and formative evaluation. The second step of Walker's method is to clarify project objectives, that is to write objectives for the system in a way that they can be measured. While writing measurable objectives is outside the scope of this work, it has been examined by others (St. Clair & Baker, 2000) and must be considered in the first and second steps of creating a WAA model.

Walker's third step is to create a model of change which is "the specific set of relationships that one believes connects the intervention to the achievement of the impact objectives of the project" (Walker, 1997). He states that while creating a model of change "sounds like a simple concept, it is often the weakest element of an evaluation plan. Development of a clear and correct model of change is the most critical step in the development of a sound evaluation plan" (Walker, 1997). Walker provides a sample of a model of change, but little guidance on how to create one for other learning systems. Also, physical actions, cognitive activities, and system goals are presented in the model without distinction between them, though in his example there is a sense of how lower levels of abstraction are means to the higher ones. Also, the model presented is vague, using statements such as "students use materials" rather than specifying what actions students will take with the materials. He does provide some guidance on building a model of change:

> "The important point here is that the set of relationships theorized to exist between the intervention and the goals of the project must be clearly defined. …The more specific you are in developing your model of change, the more useful the information generated by the evaluation will be" (Walker, 1997).

WAA provides a method that leads the evaluator to be specific when developing the model and identify the set of relationships between system elements and the system goals. In addition, the WAA method described in chapter three specifies a method to do this while Walker does not. The WAA model leads the evaluator to be more specific about the system than Walker's method, as can be seen by comparing the general statements Walker uses in his model with the more specific statements used in the WAA model in the previous section. Walker's method also does not specify the nature of each relationship identified, though most appear to be means-end relations. This is in contrast to WAA where the types of relationships between system elements are defined. Walker also makes no distinction between roles in his model of change and how one role influences others. Another difference is that Walker only uses this model at this step in the evaluation, whereas in evaluation with WAA the evaluator uses the model extensively for both planning and formative evaluation.

Steps four and five in Walker's method are to select what measures to use to evaluate the system and identify ways to collect those measures. This is a key step also in performing formative evaluation with WAA. In both methods, the evaluator must identify what aspects of the system need to be measured to determine if the system goals are met. However, in WAA, the insight each measure can provide can be assessed by examining them relative to the detailed, comprehensive model developed in planning evaluation.

Step six in Walker's method is to design the evaluation research. This step is more applicable to an evaluation involving a controlled experiment, where factors can be controlled and varied by an experimenter. In formative evaluation, the purpose is to improve an existing system rather than experimentally identify factors that affect learning. Thus, designing a strict experimental design is not necessarily part of using WAA for formative evaluation for the purpose of improving an existing system. However, when a rigorous experiment design is desired to test between multiple systems, WAA models can provide a rigorous method of describing and comparing the systems, and of analyzing the potential impact of confounding factors.

Walker's step seven is to monitor and evaluate, or carry out the evaluation activities that have been designated. Step eight is to use and report the evaluation results. In the method for formative evaluation using WAA, the evaluator collects measures and interprets them in the context of the model. Thus, the measurement activities are being performed and the model and measures are used for evaluation.

The other formative evaluation methods referenced above are similar to Walker's. They are more specific in some aspects, especially data collection, but list essentially the same steps as Walker. The discussion above shows that the method of using WAA for formative evaluation is what the literature prescribes for formative evaluation activities. Also, this method is more specific in many points than those identified in the literature.

5.4 Formative Evaluation Using Work Action Analysis

To use WAA for formative evaluation, the evaluator's model as represented within the WAA framework for planning evaluation can provide the context for selecting and interpreting measures taken in the course. This method is described below for the portion of ISyE 4009 described above for planning evaluation.

5.4.1 Measures Collected Through ITWeb

Once the WAA model has been developed, it can be used as a basis for selecting which measures to collect. Some elements will lack measures are they are not feasible to collect in a formative evaluation, and not every element in the model needs an associated measure. Since elements are related to each other, the performance or effectiveness of many elements can be inferred from measures on other elements. For example, a process measure can be collected to determine if students have downloaded and therefore likely have read the assignment. Also, it can be inferred that, if a student turns in the work for an assignment, that student has read the assignment. The relation between these elements is indicated in the model so that data on the grade can be used to infer the action of reading the assignment.

As noted in chapter two, educational measures can be difficult to collect, and there are several constraints that prevent more evaluation activities from being performed. An evaluation system like that described in chapter four alleviates the constraints on what measures can be collected by removing much of the administrative burden of measurement collection and by allowing measures to be collected on learning events that take place through the CMS outside the classroom.

The measures collected and used here are summarized in Table 7. The evaluation system of ITWeb described in chapter 4 was used to collect these measures; specific information on their implementation for this test case is presented in the following subsections.

Table 7: Measures Collected on Each Assignment for Formative Evaluation

Perception Measures
- Student ratings of associated topics
- Survey results on associated topics

Performance Measures
- Grades on the homework assignment
- Grades on the peer review assignment (if applicable)
- Assessment results on associated topics

Process Measures
- Total number of logins between lectures and assignment due date
- Percent of associated topics hit between lectures and assignment due date
- Total hits on associated topics between the lecture and the assignment due date divided by the number of topics
- Total hits on associated topics after the assignment due date divided by the number of topics
- Number of peer review comments left (if applicable)
- Total number of hits in the peer review component (if applicable)
- Total number of hits on the assignment feedback page

5.4.1.1 Perception Measures

ITWeb allows the evaluator to administer a survey to students on any topic stored in the CMS's database. The surveys were designed to give some insight into what physical actions and cognitive activities students were engaging in to learn the content. Thus, the following questions were administered after the first midterm exam and evaluated the three topics with the lowest scores on the exam (topics 410, 434, and 438).

1. Free response: “What actions did you take to study the material for this topic?”
2. Five-point scale: “How difficult was it to learn this topic?” (scale ranged from very difficult to very easy)
3. Multiple choice: “Which of these did you focus on most when learning this topic?”

- Memorize the facts in the material
- Reflect on the meaning of the material
- Attempt to apply the material to a new situation
- Other (free response)

In addition to surveys, students could give feedback on the effectiveness of the lecture notes provided in ITWeb through the content ratings.

5.4.1.2 Performance Measures

As described in chapter four, ITWeb allows evaluators to create pop-up assessments of students. The evaluator created all questions on the assessments to be specific to the topic each examined. For example, a question asked about topic 435 is: "True or False: Cultural models should show what is passed between people."

In addition, grades on the homework assignments are part of the normal course activities and are included in the formative evaluation. Half of the grade for homework assignments two through five is assigned based on the quality of the student's submission and half on the quality of the student's comments in the peer review component. These will be treated separately to evaluate the different aspects of the assignment activity. The grade for the first homework assignment is based solely on the students' submitted work.

5.4.1.3 Process Measures

Chapter four described the types of data that can be collected in ITWeb from student interaction with the web site and measures of students' interaction with course topics that are automatically generated by the evaluation system. Specific process measures can be designed to examine the physical actions of students identified in planning evaluation. Also, the knowledge of what topics are covered by each assignment is known, so that information about each assignment can be used in creating process measures on each topic.

Some measures directly measure student behavior during physical actions that can only take place while using ITWeb. One such set of actions takes place in the peer review component. This component of ITWeb allows students to examine each other's work and to leave a comment reviewing that work. The instructor (or teaching assistant) can then view the reviews and grade them. Reviewing at least five submissions by peers was a requirement for homework assignments two through five. The number of peer review comments left by each student is one process measure of their actions. Another measure is the total number of hits from each student in the peer review component for each assignment, which indicates how much students were interacting with this component.

Another action that is available for 4009 students through ITWeb is receiving feedback on an assignment. The total number of hits per student on the feedback web page indicates how frequently students examine this feedback. This indicates whether students are engaging in the physical action of examining feedback or not.

Measures can be made of student behavior between covering a topic in class and when an assignment is due. Each assignment has multiple associated topics, and therefore multiple PowerPoint files. Also, the time each topic is covered in class and the due date of the assignment are known in ITWeb. The percent of topics associated with an assignment that a student has hit between these two times estimates how much of the content material that student has examined. The average number of hits on each associated topic during this period of time is also an estimation of how often each file is consulted. If the average number of hits is less than one, then at least some of the topics are not being viewed. If the average number is greater than one, at least some of the topics are being viewed multiple times. Estimators of the amount of interaction by students with ITWeb during this period of time can also be determined. The total number of visits to ITWeb can estimate the frequency of interactions with ITWeb as part of completing the assignment.

Finally, the number of hits on a topic after the associated assignment is due can also be determined. This measure may indicate students reviewing the content in conjunction with receiving feedback on the assignment and/or may indicate reviewing the material for another assignment, such as an exam.

Benchmark values are provided for the process measures based on the average of all the values for that measure in the course. This information would not be available during a true formative evaluation, but it is used here as a consistent baseline. In a true formative evaluation, the average for the course up to that point, and averages for that same course if taught previously, would be available as a suitable baseline.

5.4.2 Method for Formative Evaluation with Work Action Analysis

Actually performing the formative evaluation uses both a system model and measures to inform the evaluator's judgment. After collecting measures, the evaluator compares his or her expectation for each measure with the true value and places the result on the appropriate element in the WAA model. The evaluator must then consider the measures in the context of the whole model by tracing through the means-end relations within roles and correspondence relations between roles. The evaluator judges if there is a problem and the potential source of that problem. The evaluator may already have a sense that there is a problem if there is a large difference between his or her expectations and the measures, and the model can provide the context and guidance to determine where that problem exists in the system and how its effects propagate through the system.

5.4.2.1 Performing the Formative Evaluation

Detailed descriptions of following the method for formative evaluation for homework assignments one through five are below, along with the insights gained.

5.4.2.2 Evaluation of Homework One

The result for the student model is shown in Figure 51 with the associated measures relative to the evaluator's expectations. The instructor's model is shown in Figure 52. The requirements of this assignment were twofold: first, students were to set up an account in ITWeb and register for this course; second, students were to identify the skills necessary for jobs in human integrated systems via job advertisements. The first purpose does not directly involve learning and has a goal with a physical/electronic outcome as opposed to a cognitive learning outcome, thus it is not considered in this analysis.

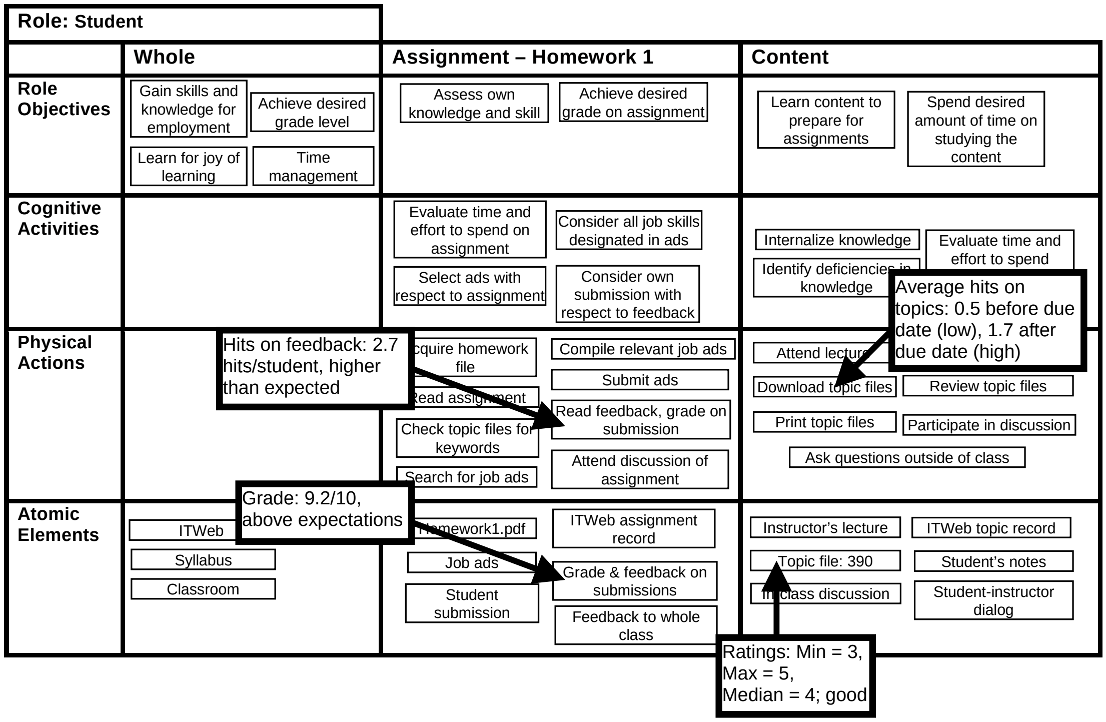


Figure 51: Model of Homework One with Evaluation Data for the Student Role

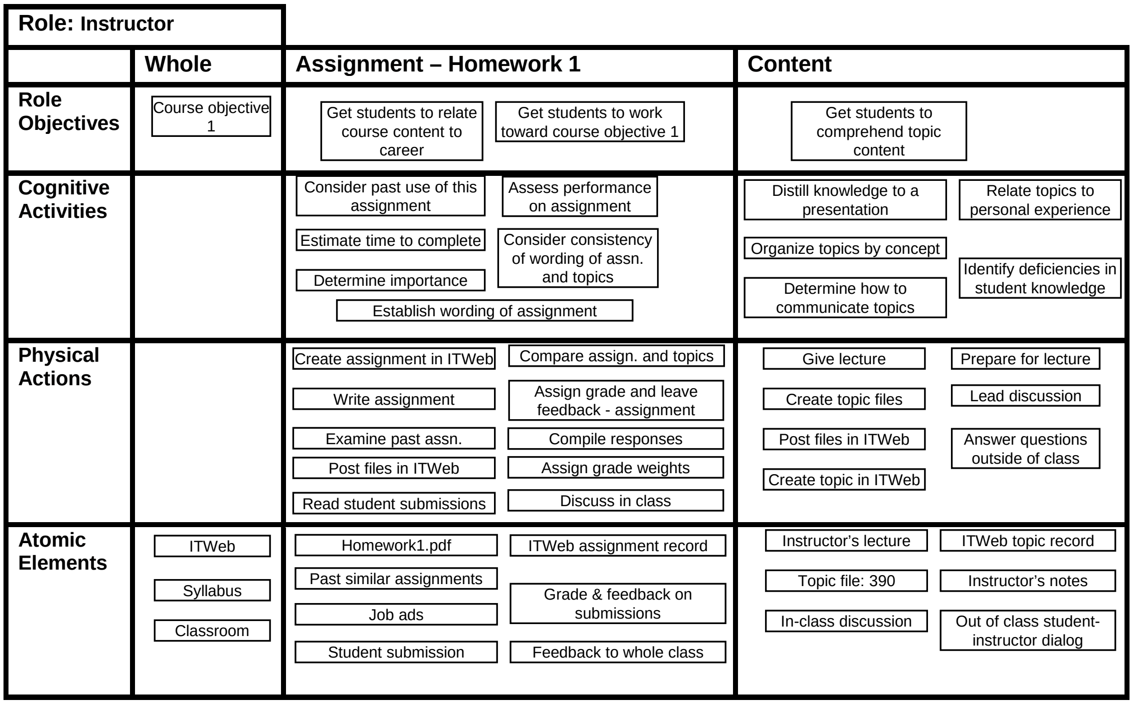


Figure 52: Model of Homework One for the Instructor Role

For this assignment, the model and measures indicate that students are generally engaging in the cognitive learning portion of this assignment as expected. Student grades are above expectations, implying that students are engaging in the related physical actions. The key physical actions related to the grade is "compile relevant job ads" which is related to the cognitive activity "select ads with respect to assignment." Part of engaging in this cognitive activity is the requirement to search for key words related to human integrated systems acquired from lecture and/or the topic file. Students rate the topic file well and so perceive themselves as understanding this topic. Students are hitting this topic less than expected, but this may be the result of students taking notes in lecture before they had access to the file in ITWeb. Thus, there appear to be no problems to students achieving the key cognitive activity "select ads with respect to assignment," and it is inferred that students are engaging in this cognitive activity.

Another cognitive activity the instructor attempts to induce in students is for students to consider all the job skills identified by their peers. As seen in the model, the instructor compiles the submissions and returns them to students as part of their feedback on this assignment. Student hits on the feedback are high, nearly three hits per student, implying that students are reading the feedback and compiled job skills. This physical action is related to the cognitive activity of "consider all job skills designated in ads." Also related to this cognitive activity is the action "review topic files", as this may be done relative to the submissions. This action is also being performed more than expected, though not to the extent of the hits on feedback. The fact that students are engaging in these physical actions implies that students are also engaging in the desired cognitive activity, though it is difficult to determine how successful they are without other measures.

No essential problems are found through the model and measures, and homework assignment one is judged to be successful. In light of this result, a formative evaluation would conclude that no interventions would be suggested at this time.

5.4.2.3 Evaluation of Homework Two

The compiled evaluation data from the measures taken on homework assignment two is found in Table 8, and the model of the student's role with the associated measures relative to the evaluator's expectations is found in Figure 53. The model of the instructor's role can be found in Figure 54. Results of the survey questions are not included in the model as they only refer to topic 410. If only the measures in Table 8 are considered, the grades indicate that there is a problem with both parts of the assignment, but not where that problem may exist in the system.

Overall, the model and measures indicate that students are having difficulty with this assignment. The homework grade is linked to and primarily based on the physical action "examine designs." This physical action is primarily linked to the cognitive activity "evaluate designs relative to content." Thus, based on the model, students are not fully engaging in this cognitive activity leading to poor grades. Part of this cognitive activity is to consider the designs relative to the content, requiring students to understand the content. So, it has means-end relations to elements in the content column, including the physical action of "review topic files." Before the assignment is due, students perceive themselves as learning the material at some level. The topic ratings are good, which is linked to the physical actions of downloading, reading and reviewing the topic files, and in turn are linked to the cognitive activity of "internalize knowledge." The assessments indicate that students have learned the content at the level of being able to recall knowledge. Students have downloaded the topic files at a lower rate than expected, which may be some cause for concern, but the assessments and ratings do indicate learning by the students. Based on this, the problem students have achieving the cognitive activity "evaluate designs relative to content" does not appear to be related to their knowledge of the content, but in the cognitive activity of evaluating designs.

Students also had difficulty with the peer review portion of this assignment. The grades are low, which are related to the physical actions "read other submissions" and "write peer review comments." Students made many more hits than expected in the peer review section of the website, implying they looked at many different submissions. However, the number of peer comments left was lower than what the assignment required. Students appear to be struggling to write comments, which is related to the cognitive activity "evaluate other's work." The model and measures imply here that students are not performing this cognitive activity.

One positive result here is that after the assignment was due, students viewed the feedback provided by the instructor and downloaded topic files at higher than expected rates. This implies students are engaging in the cognitive activities of considering their own submissions and peer review comments with respect to the instructor's feedback.

Table 8: Compiled Evaluation Measures for Homework Two

Measure	Result
Homework Grade	μ = 3.9/5 (All Homework assignments: μ = 4.4/5)
Peer Grade	μ = 3.5/5 (All Homework assignments: μ = 4.4/5)
Number of Peer Comments	μ = 4.6 comments/student (whole course μ = 4.8)
Hits on Feedback	μ = 5.5 hits/student, (whole course μ = 2.3)
Peer Review Hits	μ = 95.9 hits/student, (whole course μ = 53.4)
Survey Question 1	Topic 410: (24% response) 1 attend class 10 looked at notes and content files 6 read textbook 1 looked at project work
Survey Question 2	Topic 410: (24% response) 45% Part hard, part easy 54% Somewhat easy
Survey Question 3	Topic 410: (24% response) 9% Memorize facts 72% Reflect on meaning of material 18% Attempt to apply to new situations
Assessments	Topic 406: 87% correct (91%response rate) Topic 407: 100% correct (87% response rate) Topic 410: 4 questions (87%, 87%, 95%, 91% correct) (53% response rate)
Student Ratings	Topic 406: 4 ratings (8%); Min=3, Max=5, Median=4 Topic 407: 2 ratings (4%), Min=2, Max=4, Median=3 Topic 408: 1 rating (2%), rating=5 Topic 410: 1 rating (2%), rating=5
Number of Logins	μ = 4.7 logins (whole course μ = 11.4)
Percent of Topics Hit (Lecture to Due Date)	μ = 44% (whole course μ = 52%)
Average Hits/Topic (Lecture to Due Date)	μ = 0.8 hits/topic (whole course μ = 1.1)
Average Hits/Topic (After Due Date)	μ = 1.5 hits/topic (whole course μ = 1.3)

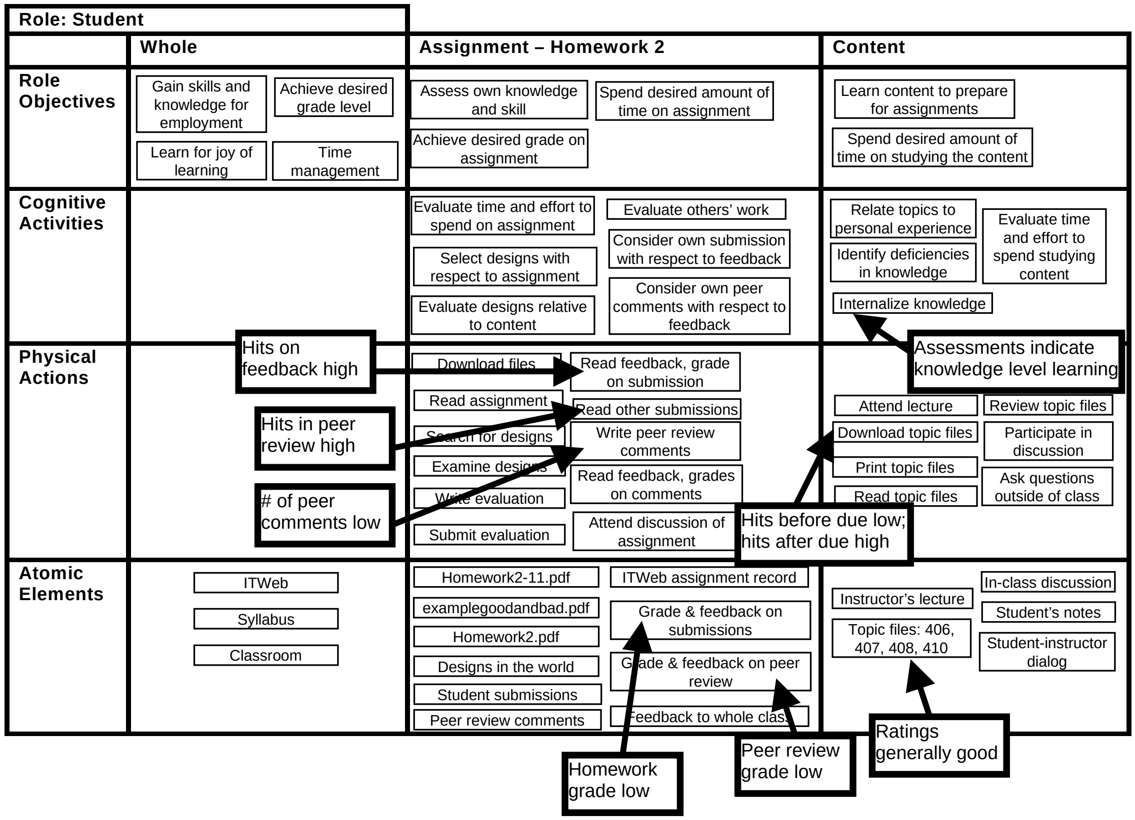


Figure 53: Model of Homework Two with Evaluation Data for the Student Role

Role: Instructor	Whole	Assignment – Homework 2	Content
Role Objectives	Course objectives 1, 2, and 4 Assess students' proficiency	Get students to relate content to everyday life Assess student knowledge and skill Get students to work toward course objectives 1, 2, and 4 Develop students' design evaluation skill	Get students to comprehend topic content Get students to relate content to everyday life
Cognitive Activities		Consider past use of this assignment Establish wording of assignment Consider consistency of wording of assn. and topics Identify errors Assess performance on assignment Determine importance Assess performance on peer review Estimate time to complete	Distill knowledge to a presentation Organize topics by concept Determine how to communicate topics Relate topics to personal experience Consider past lectures on topics Identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb Write assignment Examine past assn. Post files in ITWeb Read student submissions Compare assign. and topics Assign grade and leave feedback - assignment Assign grade and leave feedback - peer review Assign grade weights Discuss in class Read peer comments	Give lecture Create topic files Post files in ITWeb Prepare for lecture Answer questions outside of class Lead discussion Create topic in ITWeb
Atomic Elements	ITWeb Syllabus Classroom	Homework2-11.pdf examplegoodandbad.pdf Homework2.pdf Past similar assignments Students' submissions Peer review comments ITWeb assignment record Grade & feedback on submissions Grade & feedback on peer review Feedback to whole class	Instructor's lecture Topic files: 406, 407, 408, 410 In-class discussion Out of class student-instructor dialog Instructor's notes ITWeb topic record

Figure 54: Model of Homework Two for the Instructor Role

In summary, students are struggling to achieve the cognitive activities at the assignment level. One explanation implied from the model and measures is that this homework format may have been unfamiliar to students, and so they struggled in knowing how to complete it. Note that both cognitive activities students appeared to struggle with the most involve evaluation of designs according to criteria from the course content. Based on this formative evaluation, recommendations would include giving students more opportunities to practice these cognitive activities in and outside of class. Examples of what is required are already provided to students. Once students have more guidance in this type of assignment, it is hoped that they would be able to achieve the cognitive activities. Another possibility is to give students the same assignment with different content, giving them more practice on this type of activity. This was actually done as homework assignments two through eleven in the course are identical except for the content they cover.

5.4.2.4 Evaluation of Homework Three

The compiled evaluation data from the measures taken on homework assignment three is found in Table 9, and the model with the associated measures relative to the evaluator's expectations is found in Figure 55. The model of the instructor's role is found in Figure 56. Homework three covered the same four topics covered by homework two and included six more. Again, the survey results are not presented in the model as they only refer to a small subset of the topics covered.

As some topics are covered in both homework assignments two and three, the same pop-up assessment data is used in both but the process measures are focused on the time period for this assignment only. Thus, interpreting process measures is more problematic for this assignment as the intentions of the student are not known. For example, a student may review the topics from homework two in order to understand the feedback and mistakes on the assignment rather than to prepare for homework three. Yet, these measures still record student interactions with the CMS while learning. This may indicate a case where the modeler did not adequately capture the interactions in the system. Due to the highly related nature of these assignments in content and time, they may be modeled more accurately by including them both in the same WAA framework. In spite of this confound, the data indicate that students are downloading the content, which is a desirable behavior.

The homework assignment grade is somewhat lower than expected, and tracing through the model as in homework two, this ultimately implies that the cognitive activity "evaluate designs relative to content" is not being performed as desired. This cognitive activity is related to the physical actions in the content column (download, read, and review topic files), which in turn is related to the atomic elements of the topics and the cognitive activity "internalize knowledge." The assessments indicate that students are having difficulty at the cognitive activity level with some of the topics, and student ratings on one topic are somewhat low. Thus, students appear to be having trouble engaging in the cognitive activity "internalizing the knowledge," indicating difficulty learning the content. Given this, the model and measures indicate that the problem with the cognitive activity of evaluating designs relative to the content may be with understanding the content and not the evaluation of designs.

This is supported by noting that the model and measures indicate that students are accomplishing the cognitive activity "evaluating others' work" in the peer review portion of the assignment. Student grades are at an expected level, indicating that the physical actions are successful. This is further indicated by students leaving at least the required number of peer comments. This physical action is key to the cognitive activity "evaluate others' work," implying that it is being properly performed. Since students appear to be able to perform an evaluation of designs, the problem with "evaluate designs relative to content" is likely related to the content.

In summary, the model and measures imply that students are not successfully engaging in the cognitive activity related to learning the content for all topics, which led to students not being able to perform successfully the cognitive activity "evaluate designs with respect to the content." The elements related to the peer review portion of the assignment appear to be accomplished successfully. The recommendation based on this formative evaluation is that the instructor review the content with students, especially the topics that the assessments indicated students had not fully learned.

Table 9: Compiled Evaluation Measures for Homework Three

Measure	Result
Homework Grade	μ = 4.1/5 (All Homework assignments: μ = 4.4/5)
Peer Grade	μ = 4.3/5 (All Homework assignments: μ = 4.4/5)
Number of Peer Comments	μ = 4.8 comments/student (whole course μ = 4.8)
Hits on Feedback	μ = 2.4 hits/student (whole course μ = 2.3)
Peer Review Hits	μ = 60.8 hits/student (whole course μ = 53.4)
Survey Question 1	Topic 410: (24% response) 1 attend class 10 looked at notes and content files 6 read textbook 1 looked at project work 1 nothing Topic 434: (10% response) 2 looked at notes and content files 2 read textbook 1 looked at project work 2 nothing Topic 438: (16% response) 4 looked at notes and content files 4 read textbook 3 looked at project work 1 looked at practice exam 1 nothing
Survey Question 2	Topic 410: (24% response) 45% Part hard, part easy 54% Somewhat easy Topic 434: (10% response) 75% Somewhat easy 25% Very easy Topic 438: (16% response) 50% Somewhat hard 50% Somewhat easy

Table 9 (continued)

Survey Question 3	Topic 410: (24% response) 9% Memorize facts 72% Reflect on meaning 18% Apply to new situation Topic 434: (10% response) 25% Memorize facts 50% Reflect on meaning 25% Apply to new situation Topic 438: (16% response) 33% Memorize facts 50% Reflect on meaning 16% Apply to new situation
Assessments	Topic 406: 87% correct (91%response rate) Topic 407: 100% correct (87% response rate) Topic 410: 4 questions (87%, 87%, 95%, 91% correct) (53% response rate) Topic 433: 2 questions (76%, 96%) (53% response rate) Topic 434: 84% correct (55% response rate) Topic 435: 64% correct (55% response rate) Topic 436: 92% correct (55% response rate) Topic 437: 60% correct (53% response rate) Topic 438: 2 questions (64%, 96% correct) (53% response rate)
Student Ratings	Topic 406: 4 ratings (8%); Min=3, Max=5, Median=4 Topic 407: 2 ratings (4%), Min=2, Max=4, Median=3 Topic 408: 1 rating (2%), rating=5 Topic 410: 1 rating (2%), rating=5 Topic 433: 3 ratings (6%), Min=3, Max=5, Median=4 Topic 434: 2 ratings (4%), Min=3, Max=5, Median=4 Topic 435: 4 ratings (8%), Min=1, Max=5, Median=3 Topic 436: 2 ratings (4%), Min=5, Max=5, Median=5 Topic 437: 2 ratings (4%), Min=4, Max=5, Median=4.5 Topic 438: 3 ratings (6%), Min=3, Max=5, Median=4
Number of Logins	μ = 14.3 logins (whole course μ = 11.4)
Percent of Topics Hit (Lecture to Due Date)	μ = 29% (whole course μ = 52%)
Average Hits/Topic (Lecture to Due Date)	μ = 0.6 hits/topic (whole course μ = 1.1)
Average Hits/Topic (After Due Date)	μ = 1.6 hits/topic (whole course μ = 1.3)

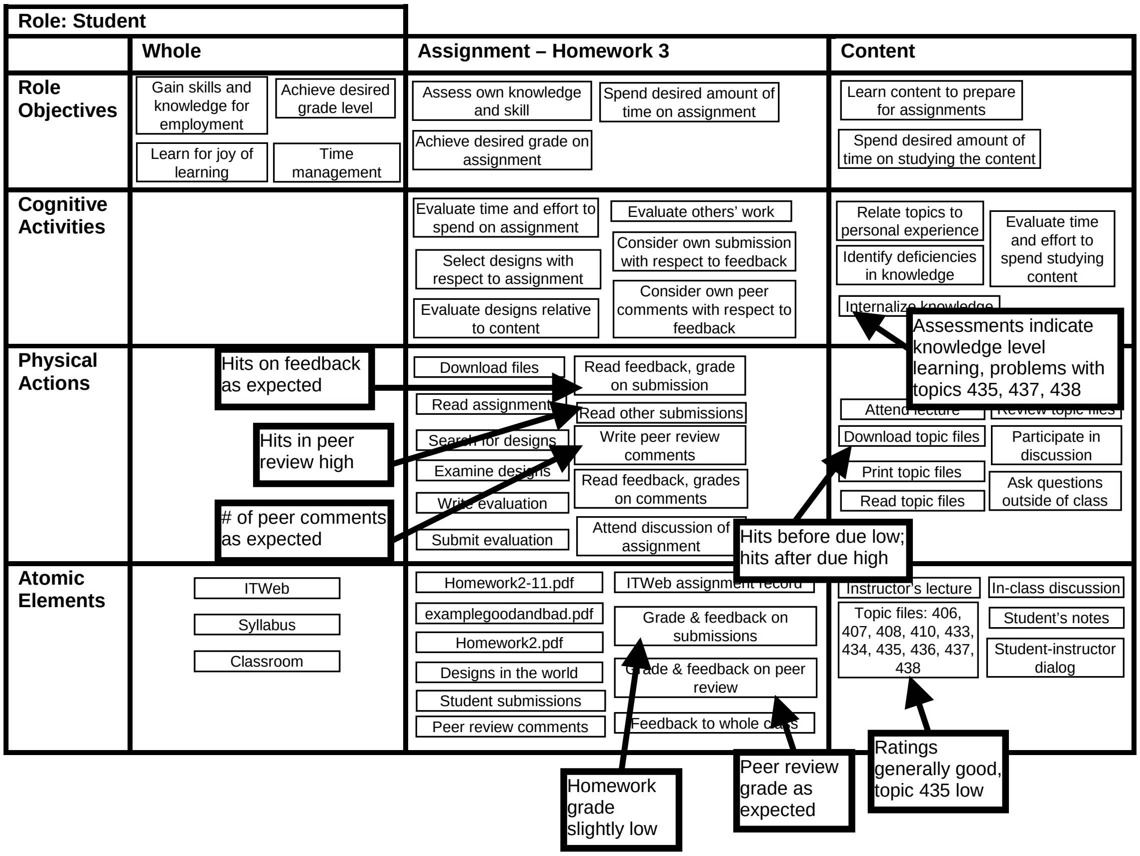


Figure 55: Model of Homework Three with Evaluation Data for the Student Role

Role: Instructor

	Whole	Assignment – Homework 3	Content
Role Objectives	Course objectives 1, 2, and 4 Assess students' proficiency	Get students to relate content to everyday life Get students to work toward course objectives 1, 2, and 4 Assess student knowledge and skill Develop students' design evaluation skill	Get students to comprehend topic content Get students to relate content to everyday life
Cognitive Activities		Consider past use of this assignment Assess performance on assignment Establish wording of assignment Determine importance Consider consistency of wording of assn. and topics Assess performance on peer review Estimate time to complete Identify errors	Distill knowledge to a presentation Relate topics to personal experience Organize topics by concept Consider past lectures on topics Determine how to communicate topics Identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb Assign grade and leave feedback - assignment Write assignment Assign grade and leave feedback - peer review Examine past assn. Post files in ITWeb Assign grade weights Read student submissions Discuss in class Compare assign. and topics Read peer comments	Give lecture Answer questions outside of class Create topic files Lead discussion Post files in ITWeb Create topic in ITWeb Prepare for lecture
Atomic Elements	ITWeb Syllabus Classroom	Homework2-11.pdf ITWeb assignment record examplegoodandbad.pdf Grade & feedback on submissions Homework3.pdf Past similar assignments Grade & feedback on peer review Students' submissions Feedback to whole class Peer review comments	Instructor's lecture Out of class student-instructor dialog Topic files: 406, 407, 408, 410, 433, 434, 435, 436, 437, 438 Instructor's notes In-class discussion ITWeb topic record

Figure 56: Model of Homework Three for the Instructor Role

5.4.2.5 Evaluation of Homework Four

Table 10 contains the compiled measurement results for homework four, and the model with the associated measures relative to the evaluator's expectations is found in Figure 57. The model of the instructor's role is found in Figure 58.

No problems are indicated by the measures in the assignment column, thus it is implied that the cognitive activities are being performed as expected. In fact, the model and measures imply that the cognitive activity "evaluate others' work" is being performed especially well. The peer review grades are higher than expected at the atomic elements level, indicating that the related physical actions of "read others submissions" and "write peer review comments" are being executed particularly well. Along with this result are measures of these physical actions indicating higher than expected hits in the peer review section and students leaving more comments than are necessary. Thus, students are engaging in the peer review activities more than expected or necessary, implying that the associated cognitive activity "evaluate others' work" is being executed repeatedly and well. One reason for this may be an interface problem with ITWeb at the time. Some students complained to the instructor that they could not easily determine how many comments they had left, as this was not readily indicated. To ensure they left a sufficient number of comments, they made comments on what they believed was more than the required number of their peers' work. While this interface problem caused frustration among the students, it may have also contributed to learning in that the students spent more effort in completing the physical actions, which could lead to higher achievement of the cognitive activities.

While students seem to be performing the assignment well, they are not uniformly performing cognitive activities well with respect to the course content. The assessment questions indicate that students may be having difficulty with the cognitive activity "internalize knowledge" for topic 441. This cognitive activity is related to all the physical actions in the content column. Students are downloading the material at a lower rate than expected, but that has been a consistent pattern in this course. Key atomic elements to these physical actions are the topic files. While ratings of these are somewhat mixed, the file for topic 441 was not rated as being difficult. This implies that the problem with this topic exists elsewhere, possibly in the elements related to the lecture (e.g., instructor's lecture, attending lecture, participating in discussion, etc.) or a lack of students reading and reviewing the material.

In summary, this analysis shows the cognitive activities are achieved, except possibly with respect to topic 441. A formative evaluation would recommend remediation on this topic and possibly further study to determine the element(s) that are the sources of the problem.

Table 10: Compiled Evaluation Measures for Homework Four

Measure	Result
Homework Grade	μ = 4.3/5 All Homework assignments: μ = 4.4/5
Peer Grade	μ = 4.8/5 All Homework assignments: μ = 4.4/5
Number of Peer Comments	μ = 5.1 comments/student (whole course μ = 4.8)
Hits on Feedback	μ = 2.6 hits/student (whole course μ = 2.3)
Peer Review Hits	μ = 65.8 hits/student (whole course μ = 53.4)
Assessments	Topic 439: 2 questions (92%, 92% correct) (55% response rate) Topic 440: 3 questions (85%, 88%, 92%) (55% response rate) Topic 441: 3 questions (92%, 68%, 70%) (51% response rate)
Student Ratings	Topic 439: 2 ratings (4%); Min=4, Max=4, Median=4 Topic 440: 1 rating (2%), rating=3 Topic 441: 3 ratings (6%); Min=4, Max=4, Median=4 Topic 442: 2 ratings (4%); Min=2, Max=4, Median=3
Number of Logins	μ = 13.9 logins (whole course μ = 11.4)
Percent of Topics Hit (Lecture to Due Date)	μ = 40% (whole course μ = 52%)
Average Hits/Topic (Lecture to Due Date)	μ = 0.7 hits/topic (whole course μ = 1.1)
Average Hits/Topic (After Due Date)	μ = 0.9 hits/topic (whole course μ = 1.3)

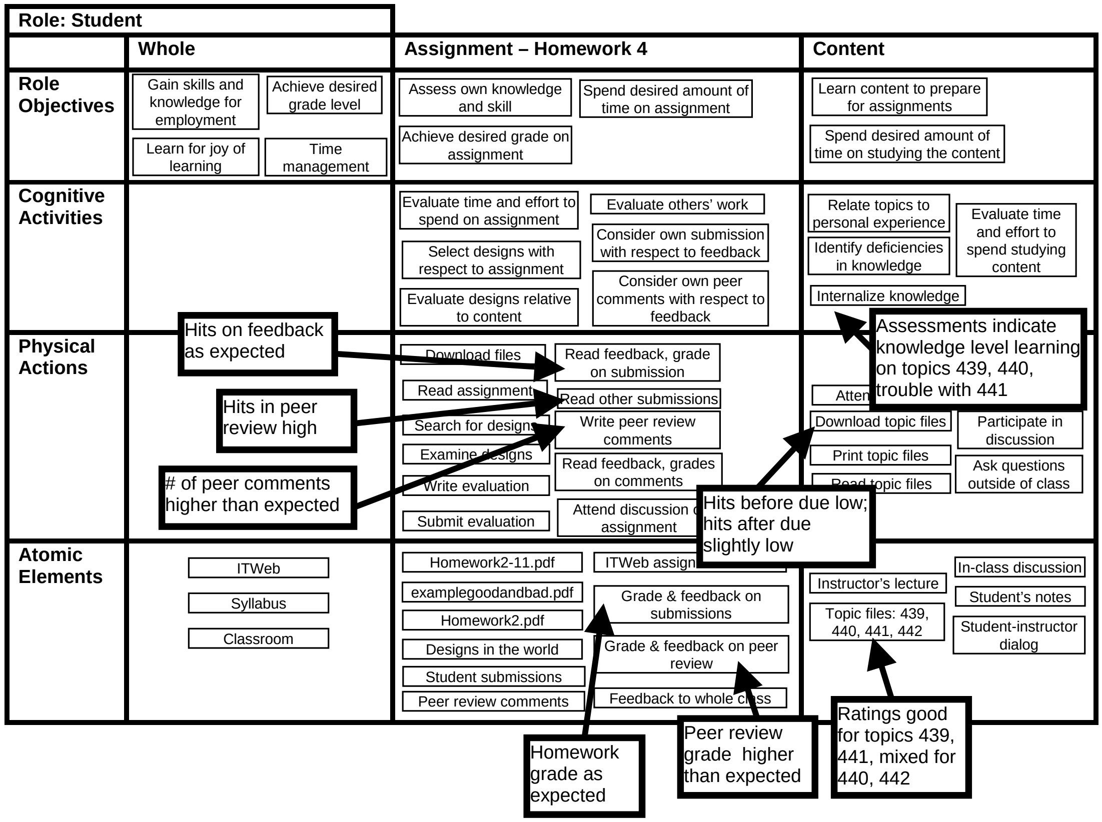


Figure 57: Model of Homework Four with Evaluation Data for the Student Role

Role: Instructor

	Whole	Assignment – Homework 4	Content
Role Objectives	Course objectives 1, 2, and 4 Assess students' proficiency	Get students to relate content to everyday life Get students to work toward course objectives 1, 2, and 4 Assess student knowledge and skill Develop students' design evaluation skill	Get students to comprehend topic content Get students to relate content to everyday life
Cognitive Activities		Consider past use of this assignment Establish wording of assignment Consider consistency of wording of assn. and topics Identify errors Assess performance on assignment Determine importance Assess performance on peer review Estimate time to complete	Distill knowledge to a presentation Organize topics by concept Determine how to communicate topics Relate topics to personal experience Consider past lectures on topics Identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb Write assignment Examine past assn. Post files in ITWeb Read student submissions Compare assign. and topics Assign grade and leave feedback - assignment Assign grade and leave feedback - peer review Assign grade weights Discuss in class Read peer comments	Give lecture Create topic files Post files in ITWeb Prepare for lecture Answer questions outside of class Lead discussion Create topic in ITWeb
Atomic Elements	ITWeb Syllabus Classroom	Homework2-11.pdf examplegoodandbad.pdf Homework4.pdf Past similar assignments Students' submissions Peer review comments ITWeb assignment record Grade & feedback on submissions Grade & feedback on peer review Feedback to whole class	Instructor's lecture Topic files: 439, 440, 441, 442 In-class discussion Out of class student-instructor dialog Instructor's notes ITWeb topic record

Figure 58: Model of Homework Four for the Instructor Role

5.4.2.6 Evaluation of Homework Five

The compiled data for homework five are found in Table 11, and the model with the associated measures relative to the evaluator's expectations is found in Figure 59. The model for the instructor's role is found in Figure 60. All measurements in the assignment dimension indicate that students are successfully completing physical actions, suggesting they are completing the desired cognitive activities in that column as well.

In the content column, the assessment measures indicate that students are having difficulty with the cognitive activity of internalizing knowledge on topics 448, 451, and 452. One physical action this cognitive activity is related to is downloading topic files. Measures of students' hits shows that they downloaded the topic files at a much lower rate than expected, even lower than has been previously seen in this course. The ratings of the files for these problem topics are up to expectations, implying that the problem is not with the files. All this suggests that the problem exists with student engagement with the material. Possibly they are not reviewing the material sufficiently to learn it, or are not downloading it at all. Measurements of the other physical actions may be able to pinpoint this problem.

In summary, this analysis shows the cognitive activities are achieved, except possibly with respect to internalizing knowledge of topics 448, 451, and 452. A formative evaluation would recommend remediation on these topics and possibly further study to determine the element(s) that are the sources of the problem.

Table 11: Compiled Evaluation Measures for Homework Five

Measure	Result
Homework Grade	μ = 4.5/5 All Homework assignments: μ = 4.4/5
Peer Grade	μ = 4.7/5 All Homework assignments: μ = 4.4/5
Number of Peer Comments	μ = 5.0 comments/student (whole course μ = 4.8)
Hits on Feedback	μ = 2.2 hits/student (whole course μ = 2.3)
Peer Review Hits	μ = 61.5 hits/student (whole course μ = 53.4)
Assessments	Topic 447: 2 questions (80%, 95% correct) (44% response rate) Topic 448: 4 questions (68%, 73%, 36%, 78% correct) (36% response rate) Topic 450: 94% correct (42% response rate) Topic 451: 64% correct (38% response rate) Topic 452: 2 questions (42%, 33% correct) (36% response rate)
Student Ratings	Topic 447: 3 ratings (6%); Min=4, Max=5, Median=4 Topic 448: 3 ratings (6%); Min=4, Max=5, Median=5 Topic 449: 3 ratings (6%); Min=3, Max=5, Median=3 Topic 450: 3 ratings (6%); Min=4, Max=4, Median=4 Topic 451: 2 ratings (4%); Min=3, Max=4, Median=3.5 Topic 452: 3 ratings (6%); Min=4, Max=4, Median=4 Topic 453: 2 ratings (4%); Min=2, Max=4, Median=3
Number of Logins	μ = 11.2 logins (whole course μ = 11.4)
Percent of Topics Hit (Lecture to Due Date)	μ = 19% (whole course μ = 52%)
Average Hits/Topic (Lecture to Due Date)	μ = 0.3 hits/topic (whole course μ = 1.1)
Average Hits/Topic (After Due Date)	μ = 0.9 hits/topic (whole course μ = 1.3)

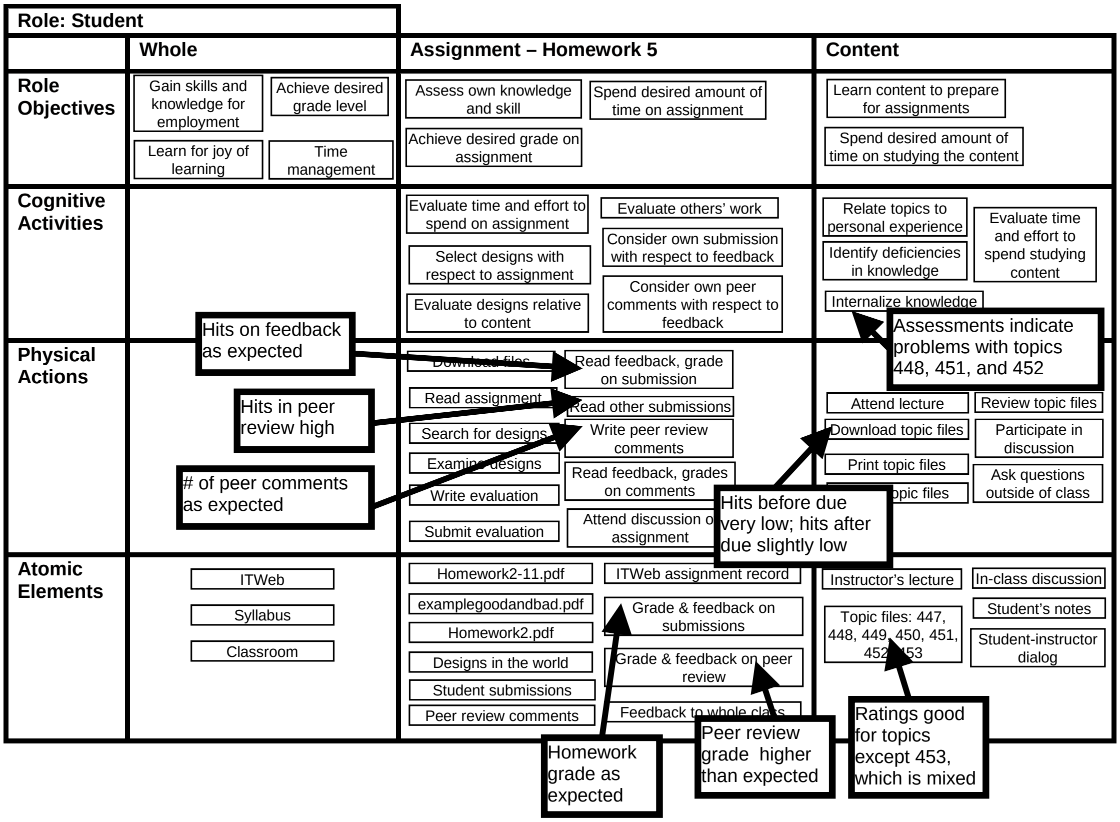


Figure 59: Model of Homework Five with Evaluation Data for the Student Role

Role: Instructor

	Whole	Assignment – Homework 5	Content
Role Objectives	Course objectives 1, 2, and 4 Assess students' proficiency	Get students to relate content to everyday life Get students to work toward course objectives 1, 2, and 4 Assess student knowledge and skill Develop students' design evaluation skill	Get students to comprehend topic content Get students to relate content to everyday life
Cognitive Activities		Consider past use of this assignment Assess performance on assignment Establish wording of assignment Determine importance Consider consistency of wording of assn. and topics Assess performance on peer review Estimate time to complete Identify errors	Distill knowledge to a presentation Relate topics to personal experience Organize topics by concept Consider past lectures on topics Determine how to communicate topics Identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb Assign grade and leave feedback - assignment Write assignment Examine past assn. Assign grade and leave feedback - peer review Post files in ITWeb Assign grade weights Read student submissions Discuss in class Compare assign. and topics Read peer comments	Give lecture Answer questions outside of class Create topic files Lead discussion Post files in ITWeb Create topic in ITWeb Prepare for lecture
Atomic Elements	ITWeb Syllabus Classroom	Homework2-11.pdf ITWeb assignment record examplegoodandbad.pdf Grade & feedback on submissions Homework5.pdf Past similar assignments Grade & feedback on peer review Students' submissions Feedback to whole class Peer review comments	Instructor's lecture Out of class student-instructor dialog Topic files: 447, 448, 449, 450, 451, 452, 453 Instructor's notes In-class discussion ITWeb topic record

Figure 60: Model of Homework Five for the Instructor Role

5.5 Summary

This chapter has demonstrated how objectives two, four, and five of this dissertation are met. Objective two is to develop a method for planning evaluation where a representation of the system is created using WAA. Section 5.1 presents such a method, meeting objective two. Objective four is to develop a method for formative evaluation using the model (resulting from objectives one and two) and measures. Section 5.3 presented such a method for formative evaluation, meeting objective four. Objective five is to demonstrate the use of WAA by performing planning and formative evaluations (from objectives two and four) on an undergraduate course using measures collected from the CMS (from objective three). Sections 5.2 and 5.4 presented the demonstrations of WAA for planning and formative evaluations of a portion of ISyE 4009 taught Spring, 2003, meeting objective five. In accordance with the scope and purpose of the analysis, a WAA model was constructed for planning evaluation. This model along with measures collected through the CMS was used for formative evaluation.

5.5.1 Insights Gained Through Model and Measures

Several insights to the system were gained through planning evaluation. First, the planning evaluation showed that the designed system elements were aligned with the role objectives and system goals. Thus, the system was predicted to meet the required goals, and the design successfully passed the planning evaluation. Second, the immediate ends were identified that each system element were expected to produce. This allows tailoring of each element to focus on achieving its immediate ends. Third, the cognitive activities that serve as the means-end bridge between objectives and physical actions were identified. While some pedagogies make these explicit, not all do and identifying their role should be a key part of planning evaluation. Fourth, the complete chain of means-end relations was identified, allowing further tailoring of each element with respect to the ultimate objectives they support. Finally, this method emphasized the importance of certain system elements that may not be obvious, such as feedback to students and student questions.

These insights represent several benefits of using the WAA method for planning evaluation. While an evaluator may derive at least some of these without WAA, the method and the structure of the model bring out all these insights. Also, WAA can be used by less experienced evaluators as it makes explicit the various aspects of the system that must be known to perform an effective planning evaluation.

Several insights were also gained during formative evaluation that used both the model and the measures. In the assignments, the evaluator used the model to identify specific cognitive activities that were not being performed as needed for the desired learning to take place, or, as with homework assignment three, were being performed even more than were expected. The model then allowed the evaluator to trace through the means-end chains to examine what elements supported these activities and consider the measures in that context. Although the measures were in some cases not able to identify where a specific problem may exist, they were able to eliminate parts of the system where the problem does not appear to exist.

The formative evaluation also revealed changes over time in that students were not initially experienced in the cognitive activities associated with assignments two through five. Evaluation of assignment two, when grades were particularly low, also showed that students examined the feedback provided, and then their performance increased in subsequent assignments.

In addition to these insights, the formative evaluation found that there may be deficiencies in the model created under planning evaluation. The fact that the average number of hits on each content file per student tends to be below one indicates that students are either ignoring the content files available through the website or they are spontaneously collaborating to distribute the files. The latter possibility is the most likely and can be included as a single physical action of "share content files among peers" in the role of the student or can be described in greater detail, depending on the scope and level of detail required for the analysis.

As in planning evaluation, an evaluator may form some of the insights reached here based solely on the measures. However, this would require the evaluator to have a comprehensive, consistent mental model of the system. The WAA method leads the evaluator to develop a comprehensive, consistent explicit model to support coming to these conclusions.

5.5.2 Limitations of the Model and Measures

One limitation of using the method presented here for evaluation is in the coverage of the system provided by the measures. For example, in homework assignment five, the measures suggest that students are not engaging in a key cognitive activity associated with particular content. Other measures of the topic files themselves can only suggest that those are not the problem. Lacking measures of other atomic elements and physical actions, it is not possible to determine precisely where the source of the problem lies. One of the recommendations for that assignment is to attempt to measure other parts of the system, especially elements in the content column, to try and identify the source of the problem. Thus, while the model is shown here as a powerful tool to interpret the measures and guide the evaluation, it relies on adequate observability of the system by the measures.

Another limitation is that the evaluator may make an inaccurate model of the system, especially when the evaluator's mental model is incorrect. This could lead to incorrectly judging the alignment of the system and interpreting the measures. However, aspects of WAA mitigate this limitation. First, the method of creating a model leads the evaluator to be comprehensive and detailed in creating the model, potentially uncovering any inaccuracies in the model as it is developed. Second, proper use of the measures can reveal inaccuracies in the model. This is seen in the demonstration in section 5.4.2 and discussed in section 5.5.1 where students consistently downloaded content files at lower rates than expected by the evaluator. This consistent measure without evidence that students did not comprehend the material strongly suggests that the students are engaging in some activity to acquire the course notes other than what is indicated in the model.

5.5.3 Model Templates to Guide Future Model Development

Another benefit of the work in this chapter is the development of a set of WAA models that can be used as templates for implementing WAA in other learning service systems. These models will be most beneficial as templates for other learning service systems that follow a typical pattern of lectures in class and weekly homework assignments, and have content and assignments focused on the cognitive activity of evaluating designs. These templates are specific to the pedagogy of the instructor of this course and to the cognitive activities the instructor expected of the students in their assignments. As such, they do not eliminate the need for evaluators to follow the method for developing a WAA model. However, they do illustrate many generalizable aspects of common course structure, and in doing so can streamline the development of WAA models, and can provide guidance to evaluators new to WAA. In following the method given earlier in Chapter 3 to develop their own WAA model, then, course designers, evaluators and instructors can build on these templates, modifying elements to reflect their pedagogy and expectations of student cognitive activities. The complete models are presented in Appendix B, and models illustrating different student cognitive activities (framed in terms of Blooms' taxonomy) were presented earlier in Chapter 3 in Figures 14-17.

CHAPTER 6

SUMMARY, CONTRIBUTIONS, AND FUTURE WORK

6.1 Summary of Work

The five objectives stated in section 1.2 have been met by the work presented in this dissertation. The first objective is "develop a work action analysis model that can be applied to represent learning service systems, such as education." Chapter 3 describes the modeling framework of WAA (section 3.2.3), the method for creating a WAA model (section 3.4), and the application of WAA to an educational system (section 3.5). As noted in Chapter 3, the WAA model was developed by extending other cognitive engineering models, and by examining the nature of learning service systems and their commensurate modeling requirements. Specifically, WAA is a cognitive engineering method that captures both cognitive and environmental constraints inherent to all relevant roles in learning service systems. As reviewed in section 2.1.3.4, up to now there have been neither other cognitive engineering methods that capture both types of constraints in one modeling method nor methods capable of capturing the interactions of multiple roles in these types of systems. In addition, section 3.4.2 discusses how templates of models can be created.

Objective two, "develop a method for planning evaluation where a representation of the system is created using work action analysis," is met in Chapter 3 and applied in Chapter 5 to evaluation of a course. Planning evaluation using WAA is identified as the method of creating a WAA model, and this general method is identified in section 3.4. In section 5.1 this method is shown to provide the functions of planning evaluation and is an improvement over current methods, particularly due to the explicit identification of means-end relations.

The third objective, “develop a set of measures for formative evaluation that can be administered through a CMS with built-in data collection and analysis capabilities,” is met in Chapter 4. Section 4.3 describes in detail the measures and a centralized evaluation tool implemented in ITWeb. At least one of each type of measure identified in chapter 2 (performance, perception, and process) are implemented in ITWeb. These measures mitigate the major obstacle to engineering instructors performing more evaluation, i.e., the time required to perform evaluation activities (as shown in Figure 7).

Objective four, “develop a method for formative evaluation using the model and measures” is met in chapter 5. Section 5.3 describes the general method for formative evaluation documented in the literature, presents the method for performing formative evaluation with WAA, and details how the method presented here performs a formative evaluation. In addition, the WAA method is shown to be an improvement over current methods as WAA gives explicit guidance in how to model a system for evaluation and in how to select and interpret measures in the context of a system model.

Finally, objective five, “demonstrate the use of work action analysis by performing planning and formative evaluations on an undergraduate course using measures collected from the CMS” is met in sections 5.2, describing planning evaluation, and 5.4, describing formative evaluation with the measures collected in ITWeb. The demonstration of planning evaluation showed that the system goals are aligned with the other system elements. The demonstration of formative evaluation identified specific elements that were preventing the system goals from being met and resulted in recommendations for improving the system.

6.2 Contributions to the Evaluation of Learning Service Systems

6.2.1 Model and Method for Planning and Formative Evaluation

The objectives of this dissertation included developing WAA as a representation of learning service systems and developing methods to use WAA models for planning and formative evaluation.

The WAA model provides a comprehensive and detailed representation of a learning service system, identifying the specific type of relations between the various elements, roles, and system goals. The means-end, parts-whole, and roles of agents dimensions provide a framework that categorizes elements of the system with greater detail than typically provided by other evaluation methods (for example, see discussion of Grady's method in section 5.1 and Walker's method in section 5.3). Through the relations between elements, the model supports testing system alignment and interpretation of measures.

The WAA model also provides an explicit model of the evaluator's mental model of the system. This can have the same benefits as the student model created in an intelligent tutoring system (ITS) (Anderson, Boyle, & Reiser, 1985). An ITS creates an explicit model of the student's knowledge in order to identify deficiencies in that student's knowledge. Similarly, WAA requires that the evaluator make an explicit mental model of the system, which can be used to identify deficiencies in the evaluator's conception of the system. By making the evaluator examine his or her mental model, areas of inconsistency may be revealed that must be resolved. Also, the method for creating a WAA model leads the modeler to consider a comprehensive view of the system across the three dimensions of the framework.

The WAA methods presented here to perform planning and formative evaluation are also contributions. The method to create a WAA model (section 3.4) both builds a WAA model and is itself a method for planning evaluation. Evaluators who are not familiar with WAA or cognitive engineering can create WAA models using this method. Each step logically builds on the other: the method leads the evaluator to first consider the big picture of how to frame the system as a whole, then to identify individual elements in a logical order. Creating a WAA model is also a form of planning evaluation and has the characteristics of planning evaluation as identified in the literature (see section 5.1). The major advantages of this method of planning evaluation include the detail and comprehensiveness of the system model, the method for enabling evaluators who are not expert in WAA to create an accurate, detailed, and comprehensive model, and the model's ability to explicitly analyze the alignment of the system.

Similarly, the method for formative evaluation presented in this dissertation provides guidance to evaluators in applying WAA for formative evaluation. This method has the characteristics identified in the literature of formative evaluation (see section 5.3). Evaluators who are not familiar with WAA or cognitive engineering can follow this method. The method for formative evaluation leads the evaluator to interpret the measures taken on the system in the context of the structure of the system as represented in the WAA model. This allows the evaluator to trace any problems detected to their potential source and back to the role objectives and system goals that are not being met, which is especially beneficial when the source of the problem is not easily measured directly. This method also has the advantage of following directly from the model building method of planning evaluation, making a comprehensive evaluation method that uses a consistent model through the stages of planning and formative evaluation.

6.2.2 Educational Alignment as Examining Means-End and Correspondence Relations

As discussed in section 5.1, the alignment of goals and the means to achieve them in an educational system is seen as an important part of planning evaluation; however, there are no specifications in the education literature for how to judge if a system is aligned. This dissertation has demonstrated that determining if an educational system is aligned is equivalent to determining if all system elements within a role are related via means-end relations and if the system goals will ultimately be achieved by the actions and activities of all the roles linked by correspondence relations.

6.2.3 Application to Other Learning Service Systems

This test case of WAA has shown how it can be applied for planning and formative evaluation in an undergraduate engineering course. The same methods for these types of evaluation could be applied to other aspects of university education in general, including undergraduate and graduate courses in various fields. WAA could also be used in other types of education and training that fall under the definition of learning service systems. WAA is designed to apply to any learning service system, which is a system where the service of teaching knowledge or cognitive skills is provided by at least one agent to at least one other agent desirous of learning them. These systems are characterized by the levels of abstraction as described in 3.2.2.2, where cognitive activities are the immediate means to achieve role objectives. By this definition, learning service systems include typical university courses since their purpose is for an instructor to teach students knowledge and cognitive skills, and cognitive activities are the immediate means to achieve the role objectives (as was the case in the system in chapter five). Other systems, such as much of K-12 education, can also fall under this definition.

In addition, by capturing the roles of cognitive agents in the system, not just humans, WAA opens up analysis to more detailed analysis of learning service systems where the cognitive agents may or may not be human. In education, a role can be held by a non-human agent, such as an intelligent tutoring system (ITS) (Anderson, Boyle, & Reiser, 1985). An ITS has the objective of making its model of the student conform to the expert model. It performs computational activity that is (arguably) comparable to cognitive activity in determining deficiencies in the student's model and interacts with the student via a computer interface. Thus, in modeling an educational system with an ITS, WAA would treat the ITS as having the role of a cognitive agent, and so requires the system elements and goals for that role to be explicitly represented alongside other roles.

6.2.4 Benefits of Model Templates

Templates of WAA models can provide several benefits. First, they can serve as an instructional tool for modelers who are not familiar with WAA. The templates could serve as examples of how the WAA method is applied to create a guide for various situations, giving the modeler a sense of how to develop the framework, populate it with appropriate elements, and identify relations between elements, all appropriate to the system. Second, the template can drive the modeler to be more comprehensive in the final model. Well-developed templates can cover aspects of a system that a modeler may not otherwise consider. Third, the templates can save time in developing the models. If an appropriate template can be found for a given system, that saves the evaluator time in developing the model, which can be spent in refinements to the model or the evaluation. Fourth, the templates can be beneficial in communicating teaching methods between instructors. If a new pedagogical method is found to be useful, a model template of that method can be created and distributed to instructors. Finally, if a course is being transferred between two instructors, the instructor who previously taught it can give the model of the course to the new instructor. In this sense, the new instructor has a template of the course that can be modified as desired.

A database of templates has been started by this dissertation. Appendix B presents the models as created for the portion of ISyE 4009 studied in this dissertation and can serve as templates for other modelers as they create WAA models. As more learning service systems are modeled, a database of templates can grow as well.

6.2.5 Work Action Analysis for Summative Evaluation

This dissertation has demonstrated the use of WAA for planning and formative evaluation, yet its use need not be limited to these forms of evaluation. The purpose of summative evaluation is to determine whether the system has met its goals once it has completed its life cycle. As opposed to formative, which focuses on finding improvements, summative tends to judge the success of the system to determine if it should be implemented again. While their purposes are different, the methods to carry out formative and summative evaluations are very similar, as noted in section 5.3. A WAA model of an educational system can be used for summative evaluation in the same way it is used for formative evaluation; the model serves as the context for selecting and interpreting the measures. The summative evaluator can take the measures collected over the course of the system's life cycle (including its end), associate them with appropriate elements in the model, and use judgment to determine whether the goals of the system were met.

There are several advantages to summative evaluation with WAA as compared to formative. In summative evaluation, more measures will be available than during formative evaluation since all the evaluation measures collected over the entire course can be used together. Also, measures that are collected slowly or over time, which would not be useful for formative evaluation, can be used in a summative evaluation. With the availability of historical measures and measures that would otherwise not be used in formative evaluation, trends can be seen over time when going through the method of evaluation. Also, if WAA was used for planning and formative evaluation, the model and at least some measures would already be available for summative evaluation. As such, WAA can serve as a consistent structure for planning, formative, and summative evaluation of learning service systems, providing a comprehensive evaluation method that encompasses their entire life cycle.

6.2.6 Collection of Evaluation Measures Via a Course Management System

Another contribution to education is the identification of multiple types of measures that can be used for formative evaluation and administered through a CMS. As noted in section 4.2, there are several advantages to collecting measures via a CMS, including capturing data outside the classroom and being able to automate much of the administrative process of collecting the data and compiling the results. In addition, implementing these measures in ITWeb in a centralized evaluation tool brings these benefits immediately to instructors using that CMS. The addition of automated analysis of the data by generating statistics and graphs further supports the evaluator in interpreting the data.

It should be noted that formative evaluation using WAA is not restricted to a given set or class of measures, nor just to measures collected via a CMS. Other measures of student learning that are selected with respect to the model can be collected, including student interviews, focus groups, and classroom observation. For formative evaluation, the results of these measures must then be integrated with the model and attached to the particular elements they examine, just like measures collected via the CMS.

Likewise, the use of the measures developed in chapter four is not restricted to evaluation using WAA. Measures collected via a CMS can be used for other methods of formative and/or summative evaluation, as long as they are properly interpreted.

6.3 Theoretical Contributions of Work Action Analysis

WAA makes several theoretical contributions to cognitive engineering and educational evaluation. Key contributions are listed below.

6.3.1 Distinctions and Relations Between Roles

As noted in section 2.1.3.1, roles of different agents have been examined in work domain analysis, a cognitive engineering method. However, the treatment of roles does not identify how the roles interact and influence each other. Also, work domain analysis assumes that all roles perform work in the same work environment. This thesis proposes that, instead of viewing a learning service system as a single work environment where multiple roles interact, each individual role can be viewed as having its own work environment, complete with its own objectives, cognitive activities, physical actions, and atomic elements. This view is captured by WAA which represents roles as each working within its own environment. Each role is modeled here as influencing others by creating or changing atomic elements in its own environment and passing them to other roles. This highlights the sometimes-indirect mechanisms by which any one agent can steer the system towards its goals. In many forms of education, for example, the instructor cannot directly determine the physical actions, cognitive activities, and objectives of the students. Instead, the instructor must design atomic elements (e.g., assignments, lectures, conversations during office hours) that will be incorporated into the environment of the student to influence their behavior in the desired way.

6.3.2 Agents and System Goals

Another insight related to roles is concerning role objectives and system goals. This thesis notes the distinction between the objectives of each role and the overall system goals. These may overlap, but they need not. In a learning service system, not every role must explicitly have a system goal as its role objective. This introduces the question of how can system goals be met by a role that is not explicitly trying to meet them? The answer is that those roles that are explicitly seeking system goals influence other roles to meet the system goals. For example, the students' role does not necessarily have the system goals as role objectives, while the instructor's role does. Thus, the instructor must influence the students to engage in physical actions and cognitive activities that should lead to the course objectives being met.

This insight provides a new viewpoint of systems with multiple interacting agents. Each agent has its own objectives that drive its behavior, and these objectives may or may not overlap with the broader system goals. An important task of the agents who are attempting to meet system goals is explicitly modeled in this thesis as influencing the other roles so the system goals are met. Thus, fundamental components of a model of learning service systems include the objectives of each agent, whether any of those objectives correspond to system goals, and what means are used to influence other agents to meet system goals.

6.3.3 Examining Cognitive and Environmental Influences Together

As discussed in section 3.2.1, both the environment and cognition influence behavior. While one may be more prominent than another in a given system, both influence behavior and should be modeled together. In Simon's illustration of the ant on the beach (Simon, 1981), discussed in section 2.1.1.2, the ant's behavior is driven both by internal objectives to reach a certain location and by the external constraints of the physical shape of the beach.

This thesis identified the interplay between the environmental and cognitive aspects of learning service systems. Though unobservable, the cognitive activities are the immediate means to achieve learning service systems' goals. These cognitive activities cannot be carried out without physical actions, and the physical actions require atomic elements from the work environment. In a WAA model, these relations are seen in the agent-environment means-end dimension, where each influences the other through means-end relations. Also, the WAA model reveals that, for agents to interact with each other in this type of system, they must do so through the atomic elements in the work environment because they cannot directly affect another's cognitive activities.

This insight enables a comprehensive, detailed model of the system, including cognitive activities that are not normally observable, and the relations between system elements created by the interplay of the environmental and cognitive elements. In doing so, this model captures a fundamental aspect of learning service system dynamics, i.e., the particular relation between environment and cognition that they require to meet their system goals. This aspect is not described directly in other cognitive engineering models focusing on the work environment or on the roles' tasks.

6.4 Costs and Benefits of Using Work Action Analysis

There are certain costs and benefits associated with using WAA for planning and formative evaluation, which are examined below. For a given learning service system these must be weighed to determine if the benefits for that system outweigh the costs.

6.4.1 Costs

6.4.1.1 Time and Expertise to Develop Model

Developing any comprehensive and detailed model, such as a WAA model, requires time. Also, it requires some level of familiarity with WAA and a comprehensive and detailed understanding of the system being modeled. Engineering instructors do not have experience using WAA at this time. Instructors would need to be provided with some form of training on how to use WAA and given time and support in creating models.

The costs associated with the time and expertise required to develop a WAA model are mitigated by the method to create a WAA model. The method presented in section 3.4 leads the modeler through the tasks required to create a WAA model. The order of steps is designed to build the model up in a logical fashion and provide guidance on what to do at each step.

The time and expertise requirements are also significantly reduced when model templates can be applied. Even if a template that matches the system being modeled cannot be found, the templates serve as examples of finished WAA models to guide the modeler. The models in Appendix B can serve as the beginning of a library of templates.

6.4.1.2 Time and Resources to Collect Evaluation Measures

Another cost is collecting the measures necessary for formative evaluation. If formative evaluation is to be done, the measures need to be collected in a timely manner so problems can be identified quickly. The more extensive the evaluation, the more measures must be collected. Administering evaluation measures can require a nontrivial amount of time beyond that allotted to many roles in learning service systems. For example, to administer a course survey the evaluator must create the survey, distribute it to the students, retrieve the copies, compile the results, and perform statistical analysis on the data; likewise, students must spend time completing the survey. In some learning service systems, evaluators, instructors, and students may not be given (or may perceive they lack) the time and resources needed to collect these measures.

This cost can be mitigated by electronically administered measures, such as the system described for ITWeb in Chapter 4. In this system, the evaluator must design assessments and surveys. However, the system automatically distributes these to students via the course website, collects the data, and generates summary statistics on demand. This eliminates administrative data collection activities, and enables the evaluator to use more assessments and surveys within a given amount of time and effort. Further, this evaluation system collects process measures that are also not typically practicable to collect without electronic aids.

The cost of collecting measures is also mitigated by using them within WAA. The evaluator can use the relations between elements in a WAA model to infer the meaning of a measure on one element for the elements that are related, as was demonstrated in section 5.4. This allows more insight to be gained from the measures that can feasibly be collected.

6.4.1.3 Time and Expertise for Formative Evaluation Using the Model and Measures

A third cost to performing evaluation with WAA is the time and expertise required to evaluate the model and measures. Given the WAA model and the measures, the evaluator must take the time to integrate them and interpret them. More importantly, the evaluator must have some expertise at doing so in order to interpret the measures in the context of the model rather than simply examine the measures individually.

This cost is partially mitigated by the method for formative evaluation given in section 5.3 and the demonstration of the method in section 5.4. The method steps the evaluator through the method of performing the evaluation in a logical sequence, each step building upon the previous. The WAA model itself places all the necessary components for evaluation in one place, including the model, measures, and evaluator's expectations of the measures. The demonstration of the method in this dissertation is an example of how to perform such an evaluation and so supplements the method. An evaluator can look to both this demonstration and all future ones for guidance in following the method.

This cost could be further mitigated by a software aid that supports the evaluator in building a model, integrating measures with the model, and provides guidance in interpreting the measures in the context of the model. Such an aid could be integrated into the electronic evaluation system and would reduce the time and expertise required.

6.4.2 Benefits

6.4.2.1 Developing Insight Into the System

Some benefits of making a WAA model as part of planning and formative evaluation are a result of making the evaluator's mental model of the system explicit. As noted in section 3.7, this method leads the evaluator to confront inconsistencies in his/her mental model and notice the parts of the model that are not comprehensive or are missing. Through this, the modeler can inform his/her own mental model, making it more comprehensive and consistent. With a better mental model of the system, the modeler can more accurately consider how the system will function and how a change would affect the system. In education, this can directly benefit instructors when they are the evaluators, or when they work closely with outside evaluators ot model their course.

6.4.2.2 Explicit Testing of Alignment in Planning Evaluation

Another benefit of WAA is the ability to explicitly analyze whether the system is aligned or not through the means-end relations in the WAA model. As discussed in section 5.2.3, alignment is considered an important concept in the literature, but there is little guidance for how to analyze it. The method of creating a WAA model structures analysis of the alignment of a system through the means-end and correspondence relations. Rather than rely on a variety of models and relations between different types of elements, a single WAA model shows which elements are aligned with system goals and which are not. While WAA still operates on a qualitative model, and is still interpreted by a human evaluator relative to his or her expectations, the WAA model provides one place where all aspects of alignment can be represented and analyzed.

6.4.2.3 Identifying How Well Each System Goal is Met

A related benefit is that the WAA model and measures support the evaluator in determining how well each system goal is met. In systems where the goal is a physical outcome, such as in process control, it is comparatively easy to determine if the goal has been met. However, in learning service systems, the system goals involve a change in cognition that is not directly observable. Thus, a model is required to determine if the system goals have been met. The evaluator can begin with any system goal and trace through the relations between elements to determine which elements support it. Then, given the measures in addition to the model, the evaluator can judge how well those elements performed and how well they supported the system goals.

6.4.2.4 Ability to Detect Problems

The method of using WAA for formative evaluation interprets the measures in the context of the model. This allows measures to indicate not just a specific element that is not performing as well as expected, but also through the model relations can show what elements are related, and thereby what sections of the system are impacted by the problem. Through the model and the measures, it may be possible to identify the source of a problem, as was done in section 5.4. Even if the source cannot be identified, the measures that meet or exceed expectations on other related areas of the system eliminate possible sources of the problem.

6.4.2.5 Models as a Means of Communicating the Design of Learning Service Systems

When models have been made of a system, they can be used to communicate the properties of that system to others. One situation where this would be useful, for example, is when a new instructor is teaching a course for the first time. The outgoing instructor or curricular administrator can give the new instructor the set of WAA models describing the course in more detail than provided by only atomic elements such as student handouts and assignments. The models can show the new instructor the goals of each aspect of the course, the intended cognitive activities of students, the physical actions that are designed to induce students to engage in those cognitive activities, and the atomic elements that designate the physical actions. A second situation where communicating the design of a learning service system would be beneficial is when a new pedagogical method needs to be communicated to instructors. A template WAA model can be created based on that new method and distributed to instructors, providing them with specific details on how it would be implemented and how the various system elements would interact.

6.4.2.6 Continuity Between Types of Evaluation

One last benefit is that WAA can serve as a consistent, unifying factor throughout planning, formative, and summative evaluation activities. The evaluator does not turn to different methods and techniques for each type of evaluation, but instead has the continuity of one modeling method throughout. This consistency allows the evaluator to be come familiar with one modeling method and how to use it for evaluation throughout the system's life cycle. This arrangement is more efficient as evaluators are not developing separate models at each different stage, but are using the same model as created in planning evaluation. Also, by on-going use, both the evaluator's mental model of the system and his or her evaluation judgments should become more accurate.

6.5 Future Work

This work points to several areas for future research that can improve the ability of WAA to model learning service systems, impact planning and formative evaluation techniques using WAA, and extend other cognitive engineering methods using the theoretical insights described in this dissertation.

6.5.1 Expansions to Course Evaluation

As seen in chapter four, different types of evaluation measures can be collected through a CMS, including surveys, content ratings, assessments, and statistics from the web server log. These were implemented through a centralized evaluation component in ITWeb. While these are useful, research needs to be done on other measures that can be collected through the CMS.

A potentially fruitful area for research is in measures made from web server log data. As discussed in chapter four, understanding the actions students need to perform when interacting with a CMS enables interpretation of their behavior as captured in the server log. Data from the server log can be extracted and analyzed for typical actions that can be performed on a CMS, such as participating in a discussion board, engaging in on-line tutorials, and retrieving course lecture files. Patterns of student interactions with these different components of a CMS can be compared with other measures to determine what they may indicate about student learning. The goal here is to identify patterns of student interactions that reliably indicate some aspect of student learning. While this is done in this dissertation for a course in aggregate, extending this work to detecting the relation of this behavior and learning in individuals could be a significant tool both for a human evaluator and, possibly, for automated detection of problematic behaviors across the course as a whole and by individual students.

Another area for research is the development of an interface for the centralized evaluation component that integrates the WAA model. This would reduce the workload on the evaluator over the method used in chapter five, where the model and measures were integrated on paper. Also, measures could update automatically as more data becomes available. Unlike display of the evaluation measures alone, this aspect would require more than the data and structures in most current CMSs; a means to create and display a WAA model would need to be added. Such an interface opens the way for many possible improvements to the planning and formative evaluation methods with WAA. Simple interface changes, such as color coding and/or highlighting, could indicate aspects of the model or particular measures where problems exist and that the evaluator may want to examine further. These could be based on the percentage of correct answers on an assessment, patterns of server log activity that indicate potential problems, and other comparisons between the measures and evaluator's expectations. Research into this interface can also apply ecological interface design in cognitive engineering (discussed in chapter two), using WAA as the theoretical basis for design instead of work domain analysis.

The requirements on the evaluator can be further reduced by development of a software aid that guides the evaluator through construction of a WAA model. Such an aid could lead the evaluator step-by-step through the method described in chapter three for creating a WAA model. Also, the aid could draw on a database of model templates, allowing the evaluator to select among them for a starting point. Further, if the same course was taught in a previous semester and a WAA model was created for that course, the aid could allow the evaluator to copy the previous models and update them for the current course.

6.5.2 Examining Learning Service Systems of Larger and Smaller Scope

WAA can also be applied to learning service systems with a larger or smaller scope. For example, WAA could be performed on a curriculum with adjustments to the model framework. The roles explicitly modeled may include a curriculum coordinator, academic advisor, the registrar, and others. Also, the parts-whole dimension could be divided from the whole curriculum into focus areas or stages, and then to individual courses. The same levels of the means-end dimension can be used, though with slightly different meanings when examining the larger elements in the parts-whole dimension. The objectives of the roles will reflect concerns at the curricular level, such as accreditation, preparation for professional engineer registration, and requirements for a degree. Cognitive activities and physical actions at the curricular level will address elements such as communication and problem solving skills. Physical actions may include pedagogical techniques that are used frequently or throughout the curriculum, such as team teaching, recitation meetings, and group projects, in addition to administrative duties such as advising. Atomic elements must also reflect this scope of analysis and may and student handbooks for the degree program.

At its most comprehensive, the full model framework for a course can include both a curriculum level and the more detailed course and content levels in the parts-whole dimension. While this leads to having a very large model, it provides a high level of detail for evaluating the whole curriculum. This would also allow an evaluator to evaluate the details of a course with respect to the overall curriculum goals, not just the course objectives. A model this large could potentially benefit from interfaces such as those noted earlier in section 6.5.1 to have an evaluator navigate through it.

WAA can also be applied to educational systems that are smaller in scope than a course. As an example, an individual student project team, such as in a senior design course, can be studied in detail via WAA. In this case, distinct roles may be established for individual team members (e.g., secretary, leader, presenter, etc.), along with other roles that interact with the team, such as the instructor, industry contact, factory workers, students who previously took the class, etc. The parts-whole dimension could be divided into phases of the project over time or major components of the project. The means-end levels would be very similar to those used for a course, though more detail can be given in these levels with the smaller scope.

6.5.3 Empirical Study of the Effectiveness of Work Action Analysis

An empirical study of the effectiveness of WAA for planning and formative evaluation of a course could be conducted to examine what insights and benefits would result. This would require a longitudinal study involving multiple instructors and courses over multiple semesters. It would be best to have a variety of class types to examine how WAA can perform in each. Throughout the study detailed data would need to be collected about the instructors' evaluation practices, their development of and interaction with their WAA models, their judgments on the alignment of their courses with and without their WAA models, insights gained on the operations of their courses and the source of those insights, and any changes made to the course and the reasons for the changes. This data should identify insights gained by the instructors to the dynamics of their courses and whether any change is seen in instruction and, correspondingly, student learning. One issue that must be carefully considered for this study is what information, training, and support to provide the instructors. This includes determining how much training to give the instructors before they perform their evaluations, balancing between the need to develop their skill in performing the WAA method and recreating what instruction they would likely receive in actual practice. How much information and guidance instructors will have when performing the evaluations is a similar issue, requiring balance between specially tailored handouts and what may be available to a more general audience. How much support to give during the evaluations must also be decided based on how much support would be needed for the instructors to succeed and how much would normally be available. Also, the nature and availability of that support must be a part of that decision.

6.5.4 Providing the Model to Cognitive Agents

Another potential area for research is examining the effects of providing the model to some or all cognitive agents in the system. One potential benefit is that the expectations for each agent can be communicated in detail, so that each agent can see how the physical actions and cognitive activities they should perform support their role objectives. In addition, the agents can see how their interaction with other agents leads to meeting the system goals. This may support the agents in developing an accurate, comprehensive mental model of the system and how they fit in to that system. In turn, this may support greater involvement in not only performing within the system, but also in changing the design of the system to better fit the needs of each role and the system goals. Further, giving the system model and measures to the roles allows them to engage in self evaluation. Each agent can examine its own performance relative to its role, determine if there are deficiencies in performance and where they are, and see how that affects the system goals.

In the case of an undergraduate course, for example, this could mean making a copy of the course model available to the students. While students are typically provided with course objectives in the syllabus, the model would detail how their current activities are helping them reach those objectives. If provided with their personal evaluation measures as collected by the CMS and their grades, they can perform formative evaluation on themselves and determine how well they are performing. There could also be a feedback mechanism from agents to the modeler when the model is not accurate for the role. If students are engaging in out-of-class study groups that are not organized by the instructor, they can report this so that it is included in the model.

6.5.5 Quantifying the WAA Model

An aspect of the WAA model for consideration is if the model can be quantified. Currently, WAA produces qualitative models capturing system elements and types of relations between them. While quantitative and qualitative measures may be collected in formative evaluation, they are not essentially part of the model, but used in relation to it. Just as the model is formed to reflect the evaluator's expectations, the measures collected in formative evaluation are interpreted and examined according to their relation to the evaluator's expectations. Quantifying aspects of the model would be a significant change in the essential structure of the model and would require careful consideration to what aspects of the model can be quantified and how the quantified values would be validated.

An example of one aspect of the model that can be quantified is the means-end relations between the levels of abstraction, which could be weighted. If this were done, the weight of a relation would reflect the importance of the means to achieving the end. Perhaps this would be represented as a percentage of the overall importance of each means to achieving the end (e.g., for the cognitive activity of an assignment, 5% is acquiring the assignment, 10% is reading it, 80% is doing the work required, and 5% is submitting the work). If correspondence relations are also weighted, the correspondence relations between roles must be considered as to what weights mean not only for how much atomic elements are shared, but for what an overall weighted relationship between models may indicate. Several aspects of this change must be considered, including how to determine the weights, how to interpret evaluation measurement data with respect to the weights, and how the weights would be used in formative evaluation. A question for this and any aspect of the model that may be quantified is how each quantity would be validated.

There are benefits to quantifying the model. First, a quantitative model can specify the levels of various factors in the model, rather than implying that all have equal import. Second, given quantified relations between elements, the effects of one element can be considered in light of the weights of the relations between the elements. This would lead to a numerical value of how well each role objective and system goal is met. Whether the benefits of quantifying the model would outweigh the added complexity in developing the model would require further research.

APPENDIX A

Glossary of Terms

Alignment - determining if the content, teaching methods, and assessment methods are appropriate or not in light of the educational goals (based on Biggs, 1996)

Cognitive Activity - activities that take place in the arena of the brain/mind

Cognitive Agent - entity that can interact with atomic elements guided by cognitive or computational processes, which in turn are driven by internal intentions (based on Hayes, 1999)

Cognitive Constraint - constraints on a work task that originate internally due to human cognition (based on Vicente, 1999)

Cognitive Skill - the ability to solve problems in intellectual tasks, where success is determined more by subjects' knowledge than by their physical prowess (VanLehn, 1996)

Education - the action or process of developing mental abilities, and/or skill by instruction and supervised practice (from Merriam-Webster, 2004)

Environmental Constraint - constraints on a work task associated with factors that are external to the worker (based on Vicente, 1999)

Learning Service System - a system where the service of teaching knowledge or cognitive skills is provided by at least one agent to at least one other agent desirous of learning them. Cognitive constraints are equally or more prominent than environmental constraints in shaping agent behavior, so both must be examined.

Mental Model - the models people have of themselves, others, the environment, and the things with which they interact (based on Norman, 1988)

Model - a schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics

Process Control - activity where the task of an operator is to manipulate an ongoing process so it continues to produce the desired output; domains where this is applied include manufacturing and nuclear power plan operation

Representation - in this dissertation this term will refer to the physical depiction of a model (e.g., a model that has been described in text and/or diagrams on paper)

Sociotechnical System - a system with interacting technical, cognitive, and social elements (from Vicente, 1999)

System Element - a component of a system (either real or perceived), which is depicted in a representation of a model. The nature of a single element depends on the context of that element in the framework of the modeling method. Elements may include, but are not limited to, physical objects, actions, and goals.

Work Action Analysis - a form of work analysis for the purpose of design and evaluation of learning service systems that identifies the cognitive activities and physical actions of cognitive agents and puts them in the context of the objectives and atomic elements in the environment, capturing both cognitive and environmental constraints

APPENDIX B

Cognitive Systems Models of a Portion of ISyE 4009 from Spring, 2003

Table 12: Model for Homework 1 of ISyE 4009 - Student Role

Student	Course	Assignment	Content
Role Objectives	Gain skills and knowledge for employment, learn for joy of learning, achieve desired grade level, time management	Assess own knowledge and skill, achieve desired grade on assignment	Learn content to prepare for assignments, spend desired amount of time on studying content
Cognitive Activities		Evaluate time and effort to spend on assignment, select ads with respect to assignment, consider all job skills designated in ads, consider own submission with respect to feedback	Internalize knowledge, identify deficiencies in knowledge, identify time and effort to spend studying content
Physical Actions		Acquire homework file, read assignment, check topic files for keywords, search for job ads, compile relevant job ads, submit ads, read feedback and grade on submission, attend discussion of assignment	Attend lecture, download topic files, print topic files, read topic files, review topic files, participate in discussion, ask questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework1.pdf, Solutions to HW1.ppt], job ads, student submission, ITWeb assignment record, grade and feedback to student on submission	Instructor's lecture, topic file: [introduction.ppt], in-class discussion, ITWeb topic record, student's notes, student-instructor dialog

Table 13: Model for Homework 1 of ISyE 4009 - Instructor Role

Instructor

	Course	Assignment	Content
Role Objectives	Course objective 1	Get students to relate course content to their career, get students to work toward course objective 1	Get students to comprehend topic content
Cognitive Activities		Consider past use of this assignment, estimate time to complete, determine importance, determine importance, assess performance on assignment, consider consistency of wording between assignment and topics, establish wording of assignment	Distill knowledge to a presentation, organize topics by concept, determine how to communicate topics, relate topics to personal experience, identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb, write assignment, examine past assignment, post files in ITWeb, read student submissions, compare assignment and topics, assign grade and leave feedback, compile responses, assign grade weights, discuss in class	Give lecture, create topic files, post files in ITWeb, create topic in ITWeb, prepare for lecture, lead discussion, answer questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf].pdf]	[homework1.pdf, Solutions to HW1.ppt], past similar assignments, student submissions, ITWeb assignment record, grade and feedback to student on submission	Instructor's lecture, topic file: [introduction.ppt], in-class discussion, ITWeb topic record, instructor's notes, student-instructor dialog

Table 14: Model for Homework 2 of ISyE 4009 - Student Role

Student

	Course	Assignment	Content
Role Objectives	Gain skills and knowledge for employment, learn for joy of learning, achieve desired grade level, time management	Assess own knowledge and skill, achieve desired grade on assignment, spend desired amount of time on assignment	Learn content to prepare for assignments, spend desired amount of time on studying the content
Cognitive Activities		Evaluate time and effort to spend on assignment, select designs with respect to assignment, evaluate designs relative to content, evaluate other's work, consider own submission with respect to feedback, consider own peer comments with respect to feedback	Relate topics to personal experience, identify deficiencies in knowledge, internalize knowledge, evaluate time and effort to spend studying content
Physical Actions		Download files, read assignment, search for designs, examine designs, write evaluation, submit evaluation, read feedback and grade on submission, read other submissions, write peer review comments, read feedback and grades on comments, attend discussion of assignment	Attend lecture, download topic files, print topic files, read topic files, review topic files, participate in discussion, ask questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework2.pdf], designs in the world, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [Gathering Data About Customers - The Contextual Inquiry.ppt,Principles of Contextual Inquiry.ppt, Some Focuses of Contextual Inquiry.ppt, Models That Help With Contextual Inquiry.ppt], in-class discussion, student's notes, student-instructor dialog

Table 15: Model for Homework 2 of ISyE 4009 - Instructor Role

Instructor

	Course	**Assignment**	**Content**
Role Objectives	Course objectives 1, 2, 4, assess student proficiency,	Get students to relate content to everyday life, assess student knowledge and skill, get students to work toward course objectives 1, 2, and 4, develop student's design devaluation skill	Get students to comprehend topic content, get students to relate content to everyday life
Cognitive Activities		Consider past use of this assn., estimate time to complete, determine importance, identify errors, assess performance on assignment, consider consistency of working of assn. and topics, assess performance on peer review, establish wording of assignment	Distill knowledge to a presentation, organize topics by content, determine how to communicate topics, relate topics to personal experience, consider past lectures on topics, identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb, write assignment, examine past assns., post files in ITWeb, read student submissions, compare assn. and topics, assign grade and leave feedback – assignments, read peer comments assign grade and leave feedback – peer review, assign grade weights, discuss in class	Give lecture, create topic files, post files in ITWeb, create topic in ITWeb, prepare for lecture, lead discussion, answer questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework2.pdf], past similar assignments, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [Gathering Data About Customers - The Contextual Inquiry.ppt,Principles of Contextual Inquiry.ppt, Some Focuses of Contextual Inquiry.ppt, Models That Help With Contextual Inquiry.ppt], in class discussion, ITWeb topic record, instructor's notes, student-instructor dialog

Table 16: Model for Homework 3 of ISyE 4009 - Student Role

Student

	Course	**Assignment**	**Content**
Role Objectives	Gain skills and knowledge for employment, learn for joy of learning, achieve desired grade level, time management	Assess own knowledge and skill, achieve desired grade on assignment, spend desired amount of time on assignment	Learn content to prepare for assignments, spend desired amount of time on studying the content
Cognitive Activities		Evaluate time and effort to spend on assignment, select designs with respect to assignment, evaluate designs relative to content, evaluate other's work, consider own submission with respect to feedback, consider own peer comments with respect to feedback	Relate topics to personal experience, identify deficiencies in knowledge, internalize knowledge, evaluate time and effort to spend studying content
Physical Actions		Download files, read assignment, search for designs, examine designs, write evaluation, submit evaluation, read feedback and grade on submission, read other submissions, write peer review comments, read feedback and grades on comments, attend discussion of assignment	Attend lecture, download topic files, print topic files, read topic files, review topic files, participate in discussion, ask questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework3.pdf], designs in the world, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [Gathering Data About Customers - The Contextual Inquiry.ppt,Principles of Contextual Inquiry.ppt, Some Focuses of Contextual Inquiry.ppt, Models That Help With Contextual Inquiry.ppt, ModelingWorkOverview.ppt, ArtifactModels.ppt, CulturalModels.ppt, FlowModels.ppt,PhysicalModels.ppt, SequenceModels.ppt], in-class discussion, student's notes, student-instructor dialog

Table 17: Model for Homework 3 of ISyE 4009 - Instructor Role

Instructor

	Course	**Assignment**	**Content**
Role Objectives	Course objectives 1, 2, 4, assess student proficiency,	Get students to relate content to everyday life, assess student knowledge and skill, get students to work toward course objectives 1, 2, and 4, develop student's design devaluation skill	Get students to comprehend topic content, get students to relate content to everyday life
Cognitive Activities		Consider past use of this assn., estimate time to complete, determine importance, identify errors, assess performance on assignment, consider consistency of working of assn. and topics, assess performance on peer review, establish wording of assignment	Distill knowledge to a presentation, organize topics by content, determine how to communicate topics, relate topics to personal experience, consider past lectures on topics, identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb, write assignment, examine past assns., post files in ITWeb, read student submissions, compare assn. and topics, assign grade and leave feedback – assignments, read peer comments assign grade and leave feedback – peer review, assign grade weights, discuss in class	Give lecture, create topic files, post files in ITWeb, create topic in ITWeb, prepare for lecture, lead discussion, answer questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework3.pdf], past similar assignments, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [Gathering Data About Customers - The Contextual Inquiry.ppt,Principles of Contextual Inquiry.ppt, Some Focuses of Contextual Inquiry.ppt, Models That Help With Contextual Inquiry.ppt, ModelingWorkOverview.ppt, ArtifactModels.ppt, CulturalModels.ppt, FlowModels.ppt,PhysicalModels.ppt, SequenceModels.ppt], in class discussion, ITWeb topic record, instructor's notes, student-instructor dialog

Table 18: Model for Homework 4 of ISyE 4009 - Student Role

Student

	Course	**Assignment**	**Content**
Role Objectives	Gain skills and knowledge for employment, learn for joy of learning, achieve desired grade level, time management	Assess own knowledge and skill, achieve desired grade on assignment, spend desired amount of time on assignment	Learn content to prepare for assignments, spend desired amount of time on studying the content
Cognitive Activities		Evaluate time and effort to spend on assignment, select designs with respect to assignment, evaluate designs relative to content, evaluate other's work, consider own submission with respect to feedback, consider own peer comments with respect to feedback	Relate topics to personal experience, identify deficiencies in knowledge, internalize knowledge, evaluate time and effort to spend studying content
Physical Actions		Download files, read assignment, search for designs, examine designs, write evaluation, submit evaluation, read feedback and grade on submission, read other submissions, write peer review comments, read feedback and grades on comments, attend discussion of assignment	Attend lecture, download topic files, print topic files, read topic files, review topic files, participate in discussion, ask questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework4.pdf], designs in the world, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [ProceduresAndProceduralization.ppt, PreFlightInspectionExperiment.ppt, ProcedureFollowing.ppt, ProceduresAndRolesOfHumans.ppt], in-class discussion, student's notes, student-instructor dialog

Table 19: Model for Homework 4 of ISyE 4009 - Instructor Role

Instructor

	Course	**Assignment**	**Content**
Role Objectives	Course objectives 1, 2, 4, assess student proficiency,	Get students to relate content to everyday life, assess student knowledge and skill, get students to work toward course objectives 1, 2, and 4, develop student's design devaluation skill	Get students to comprehend topic content, get students to relate content to everyday life
Cognitive Activities		Consider past use of this assn., estimate time to complete, determine importance, identify errors, assess performance on assignment, consider consistency of working of assn. and topics, assess performance on peer review, establish wording of assignment	Distill knowledge to a presentation, organize topics by content, determine how to communicate topics, relate topics to personal experience, consider past lectures on topics, identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb, write assignment, examine past assns., post files in ITWeb, read student submissions, compare assn. and topics, assign grade and leave feedback – assignments, read peer comments assign grade and leave feedback – peer review, assign grade weights, discuss in class	Give lecture, create topic files, post files in ITWeb, create topic in ITWeb, prepare for lecture, lead discussion, answer questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework4.pdf], past similar assignments, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [ProceduresAndProceduralization.ppt, PreFlightInspectionExperiment.ppt, ProcedureFollowing.ppt, ProceduresAndRolesOfHumans.ppt], in class discussion, ITWeb topic record, instructor's notes, student-instructor dialog

Table 20: Model for Homework 5 of ISyE 4009 - Student Role

Student

	Course	Assignment	Content
Role Objectives	Gain skills and knowledge for employment, learn for joy of learning, achieve desired grade level, time management	Assess own knowledge and skill, achieve desired grade on assignment, spend desired amount of time on assignment	Learn content to prepare for assignments, spend desired amount of time on studying the content
Cognitive Activities		Evaluate time and effort to spend on assignment, select designs with respect to assignment, evaluate designs relative to content, evaluate other's work, consider own submission with respect to feedback, consider own peer comments with respect to feedback	Relate topics to personal experience, identify deficiencies in knowledge, internalize knowledge, evaluate time and effort to spend studying content
Physical Actions		Download files, read assignment, search for designs, examine designs, write evaluation, submit evaluation, read feedback and grade on submission, read other submissions, write peer review comments, read feedback and grades on comments, attend discussion of assignment	Attend lecture, download topic files, print topic files, read topic files, review topic files, participate in discussion, ask questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework5.pdf], designs in the world, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [DecisionMakingOverview.ppt, StrategicAndTacticalDecisionMaking.ppt, SupportingStrategicAndTactical Decision Making.ppt, Opportunistic Decision Making.ppt,Examples of Opportunistic Decision Making.ppt, Supporting Opportunistic Decision Making.ppt, Study of Opportunistic Decision Making.ppt], in-class discussion, student's notes, student-instructor dialog

Table 21: Model for Homework 5 of ISyE 4009 - Instructor Role

Instructor

	Course	**Assignment**	**Content**
Role Objectives	Course objectives 1, 2, 4, assess student proficiency,	Get students to relate content to everyday life, assess student knowledge and skill, get students to work toward course objectives 1, 2, and 4, develop student's design devaluation skill	Get students to comprehend topic content, get students to relate content to everyday life
Cognitive Activities		Consider past use of this assn., estimate time to complete, determine importance, identify errors, assess performance on assignment, consider consistency of working of assn. and topics, assess performance on peer review, establish wording of assignment	Distill knowledge to a presentation, organize topics by content, determine how to communicate topics, relate topics to personal experience, consider past lectures on topics, identify deficiencies in student knowledge
Physical Actions		Create assignment in ITWeb, write assignment, examine past assns., post files in ITWeb, read student submissions, compare assn. and topics, assign grade and leave feedback – assignments, read peer comments assign grade and leave feedback – peer review, assign grade weights, discuss in class	Give lecture, create topic files, post files in ITWeb, create topic in ITWeb, prepare for lecture, lead discussion, answer questions outside of class
Atomic Elements	ITWeb, classroom, syllabus: [4009Spring2003syllabus.pdf]	[homework2-11.pdf, examplegoodandbad.pdf, homework5.pdf], past similar assignments, student submissions, peer review comments, ITWeb assignment record, grade and feedback on submissions, grade and feedback on peer review, feedback to whole class	Instructor's lecture, topic files: [ProceduresAndProceduralization.ppt, PreFlightInspectionExperiment.ppt, ProcedureFollowing.ppt, ProceduresAndRolesOfHumans.ppt], in class discussion, ITWeb topic record, instructor's notes, student-instructor dialog

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