A Model for the Evaluation of Innovative Engineering Courseware: Engineering an Assessment Program

**Richard H. Hall, Timothy A. Philpot, David B. Oglesby, Ralph E. Flori,
Nancy Hubing, Steve E. Watkins, and Vikas Yellamraju**

University of Missouri – Rolla

Abstract

This paper describes a general model for assessment of instructional innovations used by the University of Missouri – Rolla’s Media Design and Assessment Laboratory and an example of the model’s application. This model is based on three themes: a) iterative assessment with on-going feedback; b) triangulation of multiple outcome and process measures; and c) progressive application of multiple experimental methodologies. The model was applied in the form of two experiments that took place during the early stages of an on-going project that includes the development of multimedia modules for Basic Engineering Mechanics of Materials classes. The model’s themes and components are presented, followed by a discussion of the example experimental methodology, results, and consequent recommendations.

I. INTRODUCTION

A. Need

A great deal of time, money, and effort have gone into the development of learning technologies of all sorts in Engineering Education courseware over the years, and the pace has increased exponentially in the last decade due to the World Wide Web. Unfortunately, a substantial number of these technology-based learning innovations are integrated without any thought given to design issues, and, most importantly, without any thought to systematic evaluation of the impact of these technologies [1]. In fact, systematic evaluation of learning innovations, in general, have been greatly lacking over the years. This is particularly unfortunate because, without this type of feedback on new techniques and innovations, the most effective practices are not emphasized, and those that are ineffective remain. In response to this basic problem, some large organizations and agencies have identified evaluation and assessment as a fundamental hallmark of effective education. This is dramatically illustrated by the 2000 ABET criteria for engineering education [2], which emphasizes the importance of a recursive method of course and curriculum evaluation, a process that will surely lead to more effective practices.

It is not surprising, however, that there is still such a lack of emphasis on assessment and evaluation given some of the constraints: a) Criterion measures for learning are difficult to identify and measure; b) Laboratory studies can be artificial and field studies can be lacking in experimental control; c) Resources, such as personnel, materials, and time may be inadequate; d) Learner variables, such as ability and learning styles, may be difficult to identify and measure; e) Providing timely and meaningful formative feedback to aid development may be hampered by time constraints, and finally, f) Developers and instructors may be much more interested in developing and implementing than working with an evaluation team.

II. THE MDAL MODEL

A. Overview

Through experience with a number of engineering education courseware evaluation projects, the University of Missouri - Rolla's Media Design and Assessment Laboratory (MDAL), has developed an assessment model that addresses the many challenges cited above. The MDAL assessment model is a framework to guide the systematic application of multiple methodological and measurement tools within a variety of contexts, particularly those involving learning innovations [3, 4]. The fundamental themes of this model are:

- *Iteration*: The assessment is both formative and summative and is carried out throughout the development process, with subsequent development driven by assessment.
- *Multiple Methodologies*: Laboratory; applied in-class, and usability testing methodologies are used.
- *Triangulation of multiple measurement approaches*: Objective, subjective, qualitative, and quantitative data are collected and analyzed.

Figure 1 displays the components of the model and their interrelationship. These components are discussed in more detail below.

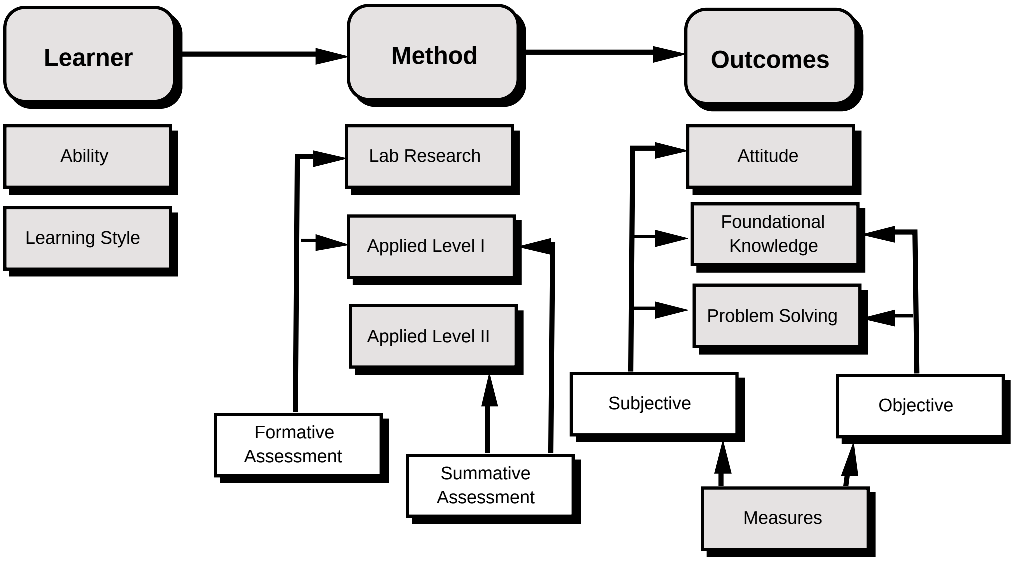


Figure 1. MDAL Assessment Model

B. Learner Variables

It is important that assessment studies take into account learner variables in order to control for learner differences, and in order to examine the interaction of individual differences with learning innovations on student performance. For example, students who are more experienced and knowledgeable may benefit more from learning innovations that emphasize flexibility and autonomy. In fact, studies of "discovery learning" indicate that such methods negatively impact low ability students [5, 6]. Similarly, there is evidence that student expertise is the most important factor in accounting for differences in performance with educational hypermedia [7-9]. As a measure of learning styles, we have used Kolb's Learning Inventory [10]. There is evidence that the abstract-concrete dimension of this inventory can serve as an effective predictor of performance with instructional hypermedia [11]. Similarly, research conducted within other MDAL projects supports the importance of LSI abstract-concrete dimension as a mediating factor in outcomes associated with instructional innovations [12].

C. Experimental Methodology

The assessment program generally employs three basic experimental methodologies. These are applied in a progressive fashion from formative to summative, as a project moves from development to application. Stage 1, basic research, is carried out simultaneously with initial software development. The interface, and components of the system, are examined through usability studies, in which the behavior of individual users is carefully examined [13], and through controlled experiments in which fundamental aspects of content and interface design are systematically varied and presented to randomly assigned groups of participants. The examples provided below are examples of this stage of research.

The second stage, *Level 1 Applied Research*, consists of research conducted within the context of classes utilizing specific components of the courseware. The third and final level of assessment, *Level 2 Applied Research*, consists of evaluation of software within the context of entire classes.

D. Outcomes

The principal outcomes that are considered across experimental methodologies are students' attitudes, foundational knowledge, and problem solving skills. Attitudes considered are variables such as perceived knowledge and knowledge awareness (metacognition) and motivation. Foundational knowledge consists of primarily factual knowledge about a given domain and problem solving consists of items that include the use of this foundational knowledge, both in terms of traditional computation problems and more advanced application problems.

E. Measures

Outcomes are assessed using subjective (qualitative and quantitative), factual/objective, and problem solving (basic and higher level) measures. The subjective measures are used to assess students' attitudes, motivation and perception of knowledge gained. The qualitative measures consist of open-ended narrative questions, and the subjective-quantitative items consist of Likert-scale (agree-disagree) statements. Questions and items are developed as appropriate depending on the goals of a given experiment. Problem solving measures consist of items used traditionally in the target classes, and, for applied experiments, class tests and a common class finals are used for summative assessment of innovations. In addition, advanced/higher-level problem solving items are sometimes developed that require students to integrate multiple concepts and to apply these concepts to novel “real life” problems, such as those a professional in the field would face.

III. MODEL APPLICATION: *TAKING THE NEXT STEP IN ENGINEERING EDUCATION: INTEGRATING EDUCATIONAL SOFTWARE AND ACTIVE LEARNING*

A. Project Overview

This project, funded by the Department of Education’s, FIPSE program, seeks to improve the means by which students learn three engineering core subjects—Statics, Dynamics, and Mechanics of Materials—through the development of innovative educational software and hands-on activities. The software development got underway in the summer of 2001 and the MDAL carried out a pair of initial assessment studies of modules for Mechanics of Materials classes in the fall of 2001. In terms of the model presented above, these studies were level 1 basic research experiments, in which one factor was varied. The factor of interest was feedback, in the form of self-quizzes (experiment 1) and a game (experiment 2). Multiple outcomes were assessed.

B. Experiment Rationale

This particular study focused on the effect of feedback used as a component of instructional software systems. The reason that this factor was selected for the initial basic research experiment was do to two contrasting factors. First, there is evidence that providing learners with feedback as a component of instructional software systems can significantly enhance learning [14], particularly for novice learners [7, 15]. Presumably, this works by encouraging metacognitive awareness [16]. On the other hand, building interactive feedback into instructional modules can often be a resource and labor intensive exercise since it requires that the content providers come up with significantly more content in the form of problems and solutions. Further, developers are required to create a more complex and interactive learning environment. Therefore, it is important to establish, from the outset, whether adding these feedback components within the context of this project will be effective enough to warrant the extra resources required for development.

C. Research Methodology

In both of these experiment students, recruited from ongoing Mechanics of Materials classes, studied courseware modules that covered Mechanics of Materials concepts that they had not yet covered in class. In both experiments students completed these experiments in computer labs in controlled conditions, observed by experimenters. After studying the target modules for thirty minutes, all students completed tests covering the materials, subjective quantitative questions, and open-ended questions.

In both experiments students were randomly assigned to one of two groups, either a feedback group or a no-feedback group. In experiment 1, students studied information covering Stress

Transformation Equations and in experiment 2 they studied information on Mohr’s circle. Thirty-five students participated in experiment 1 (15 in the feedback group and 10 in the non-feedback group). Twenty-eight students participated in experiment 2 (16 in the feedback group and 12 in the control group).

Modules included in experiment 1 (Stress Transformation Equations):

- All groups
    - Theory of stress transformations including derivation of key equations.
    - Example problem one.
    - Example problem two.
    - Method for finding correct value of angle term.
- Feedback group only
    - Quiz – sign conventions used in the stress transformation equations.
    - Study tool – using the stress transformation equations.

Modules included in experiment 2 (Mohr’s Circle):

- All groups
    - Derivation
    - How to draw a circle.
- Feedback group only
    - Game

All of the experimental study materials can be viewed at *http://www.umr.edu/~media/fipse*

D. Results

1. Outcome Measures

In each experiment, after studying, students completed a series of questions, which included completion, multiple choice, and true and false (15 questions in study 1 and 10 in study 2). In terms of the model above, these questions were mainly measures of foundational/factual questions. In addition, they responded to the following 4 questions, on a 10-point Likert scale (1 = strongly disagree and 10 = strongly agree).

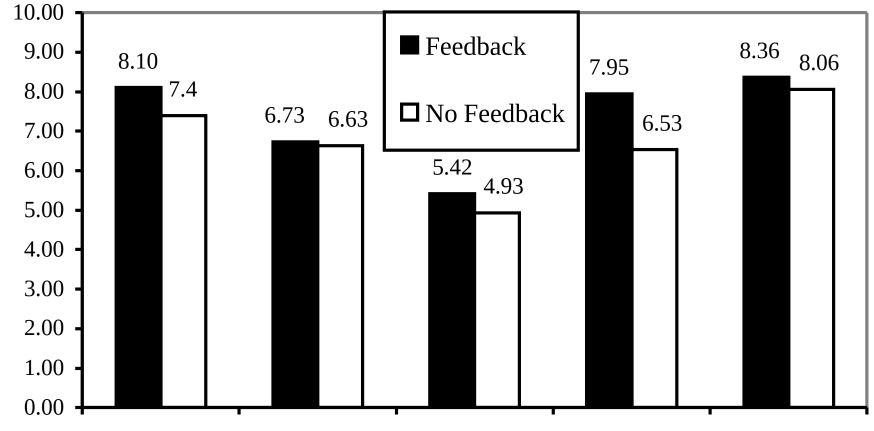
a. I learned a great deal of information from the multimedia tutorials.
b. I found the multimedia tutorials to be very motivational.
c. The web tutorials were effective in aiding me in recognizing how much I know and don't know about this topic. (Metacognition)
d. I found the navigational scheme for the web tutorials to be logical and easy to navigate.

Students were also asked to provide open-ended explanations for their ratings to each of these questions and they responded to a final open-ended question:

Please list below any other comments you can provide that will aid in the improvement of the multimedia tutorials you studied:

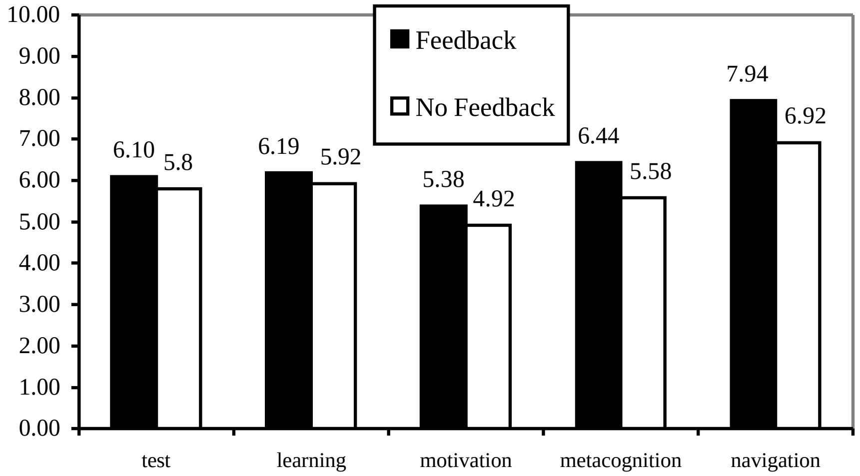
2. Quantitative Analyses

The quantitative analyses for each experiment consisted of a series of five between-subject t-tests with group (No Feedback vs. Feedback) serving as the independent variable. Test and Likert responses to each of the four subjective questions served as the dependent variables. The means for experiment 1 and 2 are listed in Figures 1 and 2 below. In all cases the mean for the feedback group was higher. However, the only statistically significant mean difference was for the metacognition question in experiment 1.



(note: y axis represents agree-disagree for subjective questions and percentage correct for test (e.g. 10 = 100%))
$^*p < .05$

Figure 2. Experiment 1 Mean test and subjective rating scores as a function of experimental group.



(note: y axis represents agree-disagree for subjective questions and percentage correct for test (e.g. 10 = 100%))

Figure 3. Experiment 2 Mean test and subjective rating scores as a function of experimental group.

3. Qualitative Analyses

Students open ended responses to each of the questions were examined with a special emphasis on identifying differences between groups. Seven major themes that emerged from the qualitative data and representative comments are listed below.

1. Students in the feedback group in experiment 1 were more positive about their perceived learning and, especially, about the degree to which it made them aware of their knowledge level (metacognition)

    - *(feedback/experiment 1):* This tutorial was easy to understand and repetitive enough for me to learn it.
    - *(feedback/experiment 1):* Made me realize I didn't know anything.
    - *(feedback/experiment 1):* Gives me a good idea of my deficiencies.
    - *(no feedback/experiment 1):* I am not sure if I did any of this right or not.
    - *(no feedback/experiment 1):* I am not sure what I did right and what I did wrong.

2. The example problems were perceived to be more useful than the theory.

    - *(feedback/experiment 1):* Explained example problems is the best feature of this program.
    - *(no-feedback/experiment 1):* I learned more from the example problems than the "lecture" portion.
    - *(no feedback/experiment 1):* The examples showed exactly how to solve the problems. Very helpful!
    - *(no feedback/experiment 1):* I like to learn from examples. I don't like to read about the derivatives.
    - *(feedback/experiment 2):* Needed a little more in examples.

3. The information should be broken up into smaller units in the experiment 1 modules (stress transformation).

    - *(feedback/experiment 1):* "… there is a vast amount of information given at once and it discourages."
    - *(feedback/experiment 1):* Would have to go slower, there's too much info.
    - *(no-feedback/experiment 1):* The tutorials were helpful yet presented too much info per page.

4. The novel components of the modules (i.e., the "Top-Drop-Sweep the Clock" method for finding the correct values for the angle term in experiment 1 and the game in experiment 2 were perceived to be some of the most effective components. (See http://www.umr.edu/~media/fipse

    - *(feedback/experiment 1):* The slight bit of humor at the beginning of the angle (+/-) tutorial helps. "Top-Drop-Sweep the Clock"…I may never forget that one…

- *(feedback/experiment 1):* The method of finding the angle has always eluded me until now.
- *(feedback/experiment 1):* It really explained the angle thing well.
- *(feedback/experiment 2):* The game was better than just reading.
- *(feedback/experiment 2):* … I liked the game.

5. The modules could serve as a good compliment to class, especially for a student who was having difficulty.

    - *(feedback/experiment 1):* I have some previous knowledge of the material but the program offered some insightful hints that will prove very beneficial as supplemental material.
    - *(no feedback/experiment 1):* If I were unable to comprehend what was going on in class this would be a good place to seek info.
    - *(no feedback/experiment 1):* It reinforced what I already knew and gave me new ways of looking at it so that I would get it right.
    - *(no feedback/experiment 2):* The tutorial makes it easier for me to pick stuff up once it is gone over in class…
    - *(no feedback/experiment 2):* The tutorials could be used as an introduction and then as a reference tool.

6. The navigation was straight forward and easy to use, with the exception that there should have been more detailed control of animations, especially the text portions in experiment 2 (Mohr's Circle).

    - *(feedback/experiment 1):* It was very easy to navigate and find my way around it.
    - *(feedback/experiment 1):* The automatic indicators that show up one after the other should be controlled by the user (one by one).
    - *(no feedback/experiment 1):* The only drawback I found was that I was trying to keep up with the animations as I was reading. I liked the top, drop, sweep animation where you had to click to proceed.
    - *(feedback/experiment 2):* Put a slider in using director or something. There didn't seem to be the controls necessary for total control.
    - *(no feedback/experiment 2):* … it was pretty self explanatory and easy. Sometimes the explanations flashed in and out too quickly.
    - *(feedback/experiment 2):* Some slides switched their animations too fast that I couldn't read all the material first. …

7. The animations, graphics, and self-paced nature of the modules added a dimension that aided learning in a way that other methods could not accomplish.

    1. *(experiment 1/no feedback):* … it allowed you to go at your own pace.
    2. *(experiment 1/feeback):* Pictures and "movies" make it more interesting.
    3. *(experiment 1/feeback):* Nice to learn at your own pace and to go back and re-read.
    4. *(experiment 2/no feedback):* I learned Mohr's circle 2 years ago. It helped remind me and was a much better way to learn than the last time.

5. *(experiment 2/feedback):* I thought it showed how the stresses were applied better and how rotating the circle worked. I like it better because you can see it.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The experiments described above illustrate basic experiments, within the MDAL model, which occurred during the early stages of development within the "Taking the Next Step" project. Therefore, the principal purpose of this study is formative – to guide further development. Based on the results reported above, the following recommendations were offered.

1. Include feedback in various forms as a component of modules to be developed in the future.
2. Emphasize example problems as a component of learning modules.
3. Break the information down into smaller units, relative to the units included in the Stress Transformation modules used in the experiment.
4. Make an effort to include novel and memorable experiences in future development as exemplified by the "Top-Drop-Sweep the Clock" method for finding the correct values for the angle term in experiment 1 and the Mohr's Circle game included in experiment 2.
5. Focus on ways in which the modules can be integrated with class materials and activities.
6. Allow the user more detailed control over playing of animations, particularly when presented as blocks of text.
7. Focus on animations that illustrate concepts that are difficult or impossible to present via traditional lecture or text.

Methodological Lessons Learned

The MDAL model is intended to be a dynamic, and in addition to the information that is gained about a particular educational tool with each experiment, we also gain important lessons with respect to the assessment methodology itself. In the case of the current project we learned that the model was generally effective, in that the set of experiments reported here did indeed provide the content providers and developers with relative specific directions on how to proceed – this is essentially the bottom line. As with any sort of enterprise of this type, there were also lessons learned, which will help us to improve our methodology. Two primary methodology changes that we recommend for future experiments are:

1. Increase sample size if possible in order to increase the power of the statistical analyses.
2. Include an objective outcome measure that is more extensive by increasing the number and variety of items, in order to increase the sensitivity of the measure to better capture different dimensions of students learning.

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Biographical Information

RICHARD H. HALL
Richard H. Hall is an Associate Professor of Information Science and Technology at UMR. He received his BS degree in Psychology from the University of North Texas, and PhD degree in Experimental Psychology from Texas Christian University. He is the director of UMR's Media Design and Assessment Laboratory, and his research focuses on Web Design and Usability Evaluation.

TIMOTHY A. PHILPOT
Timothy A. Philpot is an Assistant Professor in the Basic Engineering Department at the University of Missouri - Rolla. He completed his PhD degree at Purdue University in 1992, the M.Engr.degree at Cornell University in 1980, and the B.S. at the University of Kentucky in 1979, all in Civil Engineering. Dr. Philpot teaches Mechanics of Materials and is the PI of the US Department of Education grant that supported this work.

DAVID B. OGLESBY
David B. Oglesby is a Professor of Basic Engineering and a Research Associate for the Instructional Software Development Center at the University of Missouri-Rolla. Dr. Oglesby received a B. S. degree in Civil Engineering from the Virginia Military Institute in 1963, and M. S. and D Sc. degrees in Applied Mechanics from the University of Virginia in 1965 and 1969, respectively. He is actively involved in developing software for teaching statics.

RALPH E. FLORI
Dr. Ralph E. Flori was educated as a petroleum engineer (UM-Rolla PhD ‘87). Now an associate professor in the Basic Engineering department at the University of Missouri-Rolla, he teaches dynamics, statics, mechanics of materials and a freshman engineering design course, and is actively involved in developing educational software for teaching engineering mechanics courses. He has earned thirteen different awards for outstanding teaching and faculty excellence.

NANCY HUBING
Dr. Hubing is an Associate Professor in the Basic Engineering Dept. at the University of Missouri-Rolla. Prior to joining the BE department in August 2000, she was on the faculty of the Electrical and Computer Engineering Dept. at UMR from 1989 to 1999, and taught high school physics 1999-00. She completed her Ph.D. in ECE at NC State University in 1989. Dr. Hubing enjoys research involving educational methods and technology in the classroom.

STEVE E. WATKINS
Dr. Steve E. Watkins is Director of the Applied Optics Laboratory and Associate Professor of Electrical and Computer Engineering at the University of Missouri-Rolla. He is a member of several interdisciplinary research teams with projects addressing educational improvements in technical communication and web-based resources and the application of fiber optic sensor systems. He received his Ph.D. from the University of Texas at Austin in 1989.

YELLAMRAJU VIKAS
Yellamraju Vikas is currently a Software Support Analyst at UMR. He works in designing, developing and implementation of online education tools. He has M.S in I.E from University of Oklahoma, Norman and B.Tech. in Mech Engg from Nagarjuna University, India. He also has 3 years professional experience in Polyester/Nylon Monofilament Yarn plant in India. His present work involves research on multimedia and online learning technology for engineering applications.

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