Best Practices in the Design, Development and Use of Courseware in Engineering Education

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Abstract - **This paper discusses best practices in the design, development and use of engineering education courseware by examining the courseware recognized through the *Premier Award for Excellence in Engineering Education Courseware*. Led by NEEDS—A Digital Library for Engineering Education and supported by industry, the courseware recognized through the *Premier Award* since 1997 covers most engineering disciplines; ranges from case studies to collections of Java applets; addresses both formal and informal learning; and targets learners at multiple levels. The *Premier Award* evaluation criteria are transformed into best practices in design and development of engineering courseware. Through illustrative examples drawn from the submissions recognized by the *Premier Award*, courseware developers will be able to improve their designs leading to potential increases in learning effectiveness.**

Index Terms – NEEDS, Premier Award, courseware, learning objects, engineering education, best practices, evaluation criteria

INTRODUCTION

As engineering educators are increasingly using and developing courseware—computer-based educational materials—to use with their students, it is important to understand how high quality courseware should be designed, developed and used. By extracting and illustrating best practices from high-quality courseware, we can provide exemplars to demonstrate good instructional design and encourage improved development of courseware [15].

The *Premier Award for Excellence in Engineering Education Courseware* "recognizes high-quality, non-commercial courseware designed to enhance engineering education". The *Premier Award* is organized by NEEDS—A Digital Library for Engineering Education and sponsored by John Wiley & Sons, Autodesk, MathWorks and Microsoft Research [1]. The *Premier Award* was created to recognize the efforts of courseware developers in producing high-quality courseware and to promote and advance the evaluation of the quality of courseware. *The Premier Award* results in *Premier Courseware* selected in an annual competition by judges representing engineering faculty and students, instructional designers and industry sponsors. The judges evaluate the courseware as well as the required submission documentation that details how the courseware address the competition's evaluation criteria. The submission package typically includes assessment data on student learning and often includes testimonials of instructors and learners using the courseware. The *Premier Courseware* each have distinctive strengths, representing a breadth of styles, sophistication, pedagogies and use of multimedia, that encourages incorporation of the courseware into a range of learning environments.

This paper first provides a profile of *Premier Courseware*. Then, guided by the *Premier Award* evaluation criteria [1], the paper discusses best practices for courseware design and development by highlighting exemplary features from courseware recognized by the *Premier Award*.

PREMIER COURSEWARE PROFILE

Since 1997, seventeen courseware packages have been honored as *Premier Courseware* and six more recognized as finalist candidates. Table 1 provides a profile of the courseware recognized by the *Premier Award* by award year, primary subject area and target audience.

TABLE I
PREMIER COURSEWARE PROFILE

Title	Year	Primary Subject	Target Audience
Jeroo	2004	Computer	UG, K12
MecMovies	2004	Mechanical	UG, GRAD
Electronics Curriculum	2003	Elect. /Computer	UG,
Pavement Guide Interactive	2003	Civil	UG, PROF.
J-DSP*	2003	Elect. /Computer	UG, K12
Interactive Groundwater	2002	Civil	UG, GRAD.
Principles of Materials Handling*	2002	Materials/Metal.	UG, PROF.
BEST SiteSim*	2002	Geological	UG, GRAD.
Signals, Systems & Controls	2001	Elect. /Computer	UG
In Hot Water Case Study*	2001	Industrial/Mech.	UG
Vis-MoM*	2001	Mechanical	UG
Virtual Car*	2001	Multi-Disciplinary	UG
West Point Bridge Designer	2000	Civil	UG, K12

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Project Links	2000	Multi-Disciplinary	UG
Engineering Graphics	1999	Multi-Disciplinary	UG.
Cracking Dams	1999	Civil	UG, K12
Della Steam Plant Case Study	1998	Industrial/ Mech.	UG
MD Solids	1998	Mechanical	UG
Structural Engineering Visual Encyclopedia	1998	Civil/Construction	UG, PROF.
Virtual Disk Drive Design	1997	Mechanical	UG
Electric Drill Case Study	1997	Mechanical	UG
Bike Dissection Case Study	1997	Mechanical	UG, K12
Mars Navigator	1997	Aerospace	UG, K12

* Finalist Candidate GRAD=Graduate
UG=Undergraduate PROF=Professional

Although the target audience of most *Premier Courseware* is undergraduates, many modules were designed to be used in K-12 and by professionals.

FROM EVALUATION CRITERIA TO BEST PRACTICES

The basic concepts and principles behind the *Premier Award* evaluation criteria have essentially remained the same since their initial development in mid-1990s [4]. The evaluation criteria are arranged into a set of categories that address the instructional design, software design and content of the courseware to be evaluated. Through a process of reflection and discussion, the individual criteria are refined and focused at the end of each judging competition to describe the highest standards that can be expected from engineering courseware.

The use of the evaluation criteria can be promoted as prescriptive statements, or best practices, for the design, development and use of courseware in engineering education [4]. In the next sections we provide illustrative examples drawn from the *Premier Courseware* and finalist candidates.

Best Practices and ABET Criteria

An important facet of engineering education in the early 21st century is the relationship of teaching and learning activities to the accreditation process. A strong feature of the best practices that are described here is their relationship to the ABET accreditation criteria. The *Premier Award* evaluation criteria were developed prior to, and have evolved concurrently with, the criteria used by ABET to accredit engineering departments, often referred to as ABET Criteria 2000. The strength and broad applicability of the *Premier Award* evaluation criteria enable us to accurately and appropriately map *Premier Award* evaluation criteria (and consequently the best practices presented here) to corresponding ABET accreditation criteria. In the examples that follow we will relate the best practice to the appropriate ABET criteria.

BEST PRACTICES IN INSTRUCTIONAL DESIGN

The category of Instructional Design addresses the basic question of whether the courseware facilitates learning. It covers areas such as learning objectives, interactivity, cognition and conceptual change, content, use of multimedia and instructional use and adaptability.

The effective pedagogical application of the courseware is also a key consideration in an overall instructional design strategy. In practice, courseware are designed for various instructional uses such as in lectures presented by the professor, during recitation sections, as self-paced study, as reference material, as supporting exercises/explorations in a studio classroom environment, or as virtual experiments in a laboratory situation for the student to perform alone or in a group.

A common feature in *Premier Courseware* developers is that they have an understanding of instructional design theory that guides their development process. As evidenced by documentation and assessment data and analysis that each *Premier Courseware* developer submits along with their courseware, many developers are guided by an understanding of learning styles and learner profiles such Bloom's taxonomy, Kolb's preference models and personality indicators.

Best Practice: Courseware should have a clear statement of and support for appropriate learning objectives and goals.

A clear statement of learning objectives, combined with actual support for learning objectives and goals, enables the users of courseware, whether they be instructors or learners, to understand what the courseware is expected to cover and more importantly how to assess their use of the courseware.

In addition to meeting their individual objectives and goals, most *Premier Courseware* also contain learning objectives and outcomes that directly align with one or more ABET accreditation criteria. Most notable among these goal statements are: to increase conceptual understanding of a specific subject area; to gain calculation skills; to develop the ability to design a system, component, or process to meet desired needs, and to gain higher-level cognitive skills of reasoning, critical thinking and problem solving.

A distinguishing characteristic of *Premier Courseware* is that their developers specifically list their learning objectives and goals in their documentation and more importantly ensure that the courseware supports and enables them. The following paragraphs give examples of these principles exemplified in past award winners.

BEST SiteSim "enables students to simulate hydro-geologic or geologic [analysis based upon] site information and a budget, much as an engineer might…in the real world". With *BEST SiteSim*, students choose and integrate a variety of diverse, imperfect information, adhering to a budget, to help prepare them for solving problems encountered in their engineering career." Through the case studies and scenarios, students are able to demonstrate the learning objectives defined by the *BEST SiteSim* developers including an understanding of abstract skills such as the "application of geology and optimization of investigation strategies", "confidence in dealing with ambiguity" and an "emphasis on real-world concerns". Through the simulations in the courseware, students are able to achieve and demonstrate their mastery of the learning objective to have a "sense of vertical and lateral continuity of subsurface units".

Cracking Dams investigates how cracking occurs in dams at three different complexity levels with objectives and goals appropriate to each level. For beginning users, from Kindergarten through 4th grade and those seeking a general introduction, the courseware sets the goals of providing a basic background about dams and the causes, processes and results of cracking. These objectives are clearly stated as the learner steps through the courseware and the straightforward, non-technical descriptions make it easy for the learner to comprehend the materials and meet the learning objectives and goals. For undergraduates, *Cracking Dams* provides similar learning objectives and goals but expects the learner to demonstrate a greater level of sophistication, as expected, through complex simulations where finite element methods are used to model dam behavior during cracking.

Best Practice: The learner should be actively involved in the learning process via interaction with the courseware and other learners.

For the learner to be actively involved, courseware should respond appropriately and meaningfully to learner actions and enable the learner to control his/her own pace and mode of learning. In addition to interacting directly with the courseware, interaction with other learners as part of an entire experience is an important factor in the design and use of courseware in engineering education.

MecMovies [7] is "an extensive collection of useful examples, discussion of theory and games designed to complement introductory Mechanics of Materials Courses". *MecMovies* provides animated explanations for topics in Mechanics of Materials that require the learner to interact with the courseware. The learner can control the pace of the theoretical presentation and can view calculations or visualizations to aid in their understanding of the topic. The learner can demonstrate her/his understanding through interactive exercises that require them to enter numerical values and select appropriate visual representations of topics, such as Mohr's Circle and stresses and strains. Thus *MecMovies* is a good example of courseware activities facilitating active engagement of the learner.

Interactive Groundwater [6] is an "interactive software environment that allows the simulation of 2-D area and cross-sectional flow and transport in aquifers". *Interactive Groundwater* builds upon the level of interaction demonstrated by *MecMovies* by allowing the learner to control the learning process by performing real-time groundwater modeling, visualization and analysis tasks.

Interactions with fellow learners and instructors are an important facet of the learning process. Some *Premier Courseware* achieve this through activities designed to engage small groups of learners in discussions or interactions outside of the courseware. Case studies such as *In Hot Water* [8]—which "investigates alternatives for enhancing cooling tower performance and how decisions based in engineering theory have series financial and operational implications—and *Della Steam Plant* [8]—which illustrates problems in a turbine-generator unit and two conflicting solutions—both provide in-class activities for instructors. The *West Point Bridge Designer*—"a tool for visualizing the structural behavior and the engineering design process" of building a bridge—is the basis for a national competition in which teams of middle schools students collaborate to win a college scholarship [10].

The *Electronic Curriculum* "includes twenty-four interactive learning modules [in introductory electronics] and utilizes two novel educational tools (*Scribe* and *WebTeam*)" to facilitate interaction between learners and instructors. *Scribe* provides a means to capture, review and modify a student's use of an interactive learning module while *WebTeam* allows learners to collaboratively explore, design and test. "A great strength of the approach used in *Electronics Curriculum* is that it augments the instructor's ability to discern and address students' key conceptual blocks and to monitor student performance."

Best Practice: Learning should be integrative and transferable.

For learning to be significant and long lasting, the learner must be able to demonstrate or apply the concepts in meaningful ways and must be able to transfer that knowledge beyond what is specifically covered in the courseware. Additionally the courseware may support reflection, deep thinking, knowledge integration or making connections [5].

This best practice is a difficult one to measure as by the nature of the best practice, the learner would need to be assessed well "after" the use of the courseware to determine if the learning was "long-lasting". Nonetheless, most *Premier Courseware* provide opportunities and mechanisms that enable learning to be long lasting.

The nature of the experiential learning, which integrates experiment, perception, cognition and behavior, that occurs in case studies provides opportunities to demonstrate the development of higher-order cognitive skills—which in turn can demonstrate significant and long-lasting learning. In the *Virtual Disk Drive Design Studio* the learner enters an "immersive, virtual design environment in which the learner designs ACME Engineering's newest disk drive" In this courseware, learning can be significant and long-lasting because the learner must synthesize how the interplay of the individual technologies (e.g., read heads, platter materials, etc.) contributes to the cost and performance characteristics in the design studio [11]. In the *Bicycle and Electric Drill Dissection Multimedia Case Study,* the mechanical dissection exercises highlight the importance of functional specifications in design and how they map into specific functions and final design solutions [9]. Or in case studies such as *In Hot Water* and *Della Steam Plant* with real-world problems in actual settings, learning can be significant and long lasting because of the skills and understanding required to synthesize solutions to the problems presented [8]. Additionally, the open-ended nature of the design problems described in these case studies and the real-world examples also address important (a) to (k) ABET criteria, including to: apply mathematics, science, and engineering; to design and conduct experiments; to identify/formulate/solve engineering problems; and to design a system, component, or process to meet desired needs.

Best Practice: Content should be well chosen and structured.

It is clearly important that the content be appropriate for the intended learning objectives and audiences. It is often the case that the content should be ordered in a way as to guide the learner through it, while still allowing the learner control over her/his pace. The content should also be conveyed clearly and build upon and communicate required prior knowledge.

Ten Principles of Materials Handling "introduces the primary concepts of materials handling". The content is structured as a matrix with multiple entry points to guide users through each of four layers of practice—Discover, Explore, Contrast and Extend—for each of ten principles. The Discover Layer allows learners to discover a principle by watching a situation that clearly illustrates application of that principle. The Explore Layer allows learners to explore the principle in more depth by examining key aspects of the principle. The Contrast Layer presents cases that illustrate improper and proper application of the principle being studied. The Extend Layer discusses the same principle in a different context to promote generalization of the learning principles.

WSDOT Pavement Guide Interactive is a "virtual 'encyclopedia' of pavement knowledge". Designed to meet the needs of working professionals and university students *Pavement Guide Interactive* provides a large amount of information (275 web page, 2,500 images, 50 animations, 14 videos and 11,000 hyperlinks). The comprehensive nature of the courseware, combined with its strong internal structure and organization into modules, address the needs of both of its target audiences and serves as an example of this best practice.

*Project Link*s "provides a comprehensive environment of learning materials that link fundamental mathematics topics to applications in engineering and science". In *Project Links*, numerous modules provide the breadth that enables learners in mathematics to link to appropriate, motivating engineering examples for the mathematics, as well as provide details on the mathematics behind a wide range of engineering disciplines. The breadth, coupled with their topic groupings (either by mathematics or engineering) and detailed status indicators (indicating development status) provide a good example of well-chosen and structured content.

Best Practice: Multimedia should be used effectively to promote learning objectives and goals.

Multimedia—video, audio, animations, simulations, etc.—is an important component of courseware; it provides alternatives to purely text-based content and enables the learner to visualize content in new and novel ways, perhaps addressing a particular learning style. However, as the technology to produce multimedia continually improves and bandwidth to deliver it increases, it continues to be important to ensure that if multimedia is used: 1) it is used appropriately and not gratuitously, 2) does not provide ambiguity or misconceptions, 3) it is of high visual and aural quality and 4) it helps learners construct inter-related (e.g. visual and numerical) knowledge.

Mars Navigator—interactive courseware about Mars, Aerospace Engineering, Astronomy and the JPL Mars Missions; *Demonstration in Signals, Systems and Control* [12]—"web-based modules that contain numerous Java applets covering a wide range of concepts in signals, systems and control" and *MecMovies* each use multimedia to help the learner visualize a difficult concept. *Mars Navigator's* animations and simulations help learners visualize the Mars Pathfinder and Global Surveyor missions. The Java applets in *Demonstrations in Signals, System and Control* help the learner visualize the complex mathematics in signals, systems and control. The *MecMovies* "animations and illustrations…often reveal the internal effects produced in solid objective in ways not possible through classroom sketches or textbook drawings."

In *Visual Mechanics of Materials (VisMoM)* [2], interactive sections use multimedia effectively to visually portray relationships between different content. "Relationships between material/load and stress/strain/deformation are interactively displayed as the user moves the cursor over the different pieces of the content. This kind of interaction is designed specifically to use multimedia to develop connections scaffolds [5] between the different pieces of Mechanics of Materials puzzle"

Best Practice: The courseware should be able to be used in a variety of settings.

The use of courseware according to its design intent—stated learning objectives and audiences—would by definition be the only use the developer can evaluate and assess. Clearly the developer should plan on providing appropriate documentation and understanding of how to evaluate the use of the courseware in this setting. However, the true strength of the usability of courseware to enhance teaching and learning is that its use is not limited to the developer of the courseware. Because anyone, anywhere can make use of quality courseware, designing courseware so it can only be used in a single or very limited settings should be avoided. Often times other instructors or learners will devise novel uses of courseware that were not in the original design intent, but are nonetheless appropriate uses for the courseware.

It has been our experience with the *Premier Award* that a defining characteristic of the award-winning software is that multiple audiences can use them in multiple settings. For example, the interactive problems or exercises in the *Electronics Curriculum* might be used in a studio classroom or by a learner in the library or *West Point Bridge Designer* might be used in a national competition for middle school students or in a statics class with undergraduates. Similarly the *Structural Engineering Visual Encyclopedia*, as its name implies, might serve as a reference source used by an instructor in the classroom, or by a practicing engineer.

BEST PRACTICES IN SOFTWARE DESIGN

The category of Software Design addresses the basic question of whether the courseware functions effectively from a software standpoint. It covers areas such as engagement, learner interface and navigation, and technical reliability.

Best Practice: The courseware should hold the interest of a diversity of learners.

Beginning in the early 1990s, numerous engineering educators began to focus on the importance of learning styles and their impact on learning. Learning styles coupled with what educators observe about attention spans, expectations about "production-value", and the tone and situations presented all have a large impact on the development of courseware. These factors combine to mean that courseware must be "engaging". In other words, courseware should be: stimulating and challenging, responsive (perform quickly), visually appealing and should not contain stereotypes.

The user interface, images and colors used in courseware can contribute to the "engagement" felt by learners. In *Cracking Dams*, engineering principles are made accessible to students from kindergarten through 4th grade by the use of "Dammy the Beaver" as a guide and the illustrations used throughout the courseware. Similarly, *Jeroo* [3], which introduces learners to the basics of object-oriented programming, uses an effective metaphor of an animal, a Jeroo, that can hop in one of four directions, cannot swim and is able to carry objects in its pouch. The author's assessment has shown that this metaphor coupled with the tools provided by *Jeroo* helps learners, especially middle school girls, enthusiastically approach object oriented programming.

Best Practice: The learner (user) interface and navigation should make the courseware easy to use.

The learner, or user, interface and the navigation structure of the courseware are how learners interact with the courseware. Courseware should be consistent in its design and response to learner actions, should not confuse the learner and should enable the learner to form a "mental map" of the courseware.

An example of a good learner interface can be found in the *Virtual Disk Drive Design Studio* [11]. To provide the background information on disk drives, an image of a disk drive is used to navigate to each of the sections (e.g., read heads, platters, etc.)—not only is this engaging but it also helps reinforce the physical relationships of the components that will be helpful when "designing" ACME Engineering's newest disk drive.

Best Practice: The courseware should be technically reliable.

Technical reliability is an assumption of any good software—courseware is no exception. There should be no obvious bugs and the software should be reliable and not "crash". One of the best mechanisms to ensure reliability is for developers to perform a structured and extensive testing program so that each portion of the courseware and all of the alternatives in the possible interactions are exercised and found to operate correctly.

An extension to this best practice, is that developers should use "commonly" available tools such as Web browsers (e.g., Internet Explorer, Netscape or Firefox), document formats (e.g., Adobe Acrobat PDFs or Microsoft Word Documents), digital video formats (e.g., Apple QuickTime or Microsoft Windows Media Video/Audio) and plug-ins (e.g., Macromedia Flash) to deliver their content.

Some courseware modules are successfully implemented by using object-oriented programming languages like Java or scripting languages like javascript. In *Demonstrations in Signals, Systems and Control* [12] and *J-DSP* [14], Java Applets are used to enable on-line simulations and web-based computer laboratories for use in digital signal process courses. In *Engineering Graphics*, interactive games and quizzes are effectively implemented using Java script.

BEST PRACTICES IN USE AND ASSESSMENT

Our experiences with the *Premier Award* have also led to transformation of the evaluation criteria to include best practices in use and assessment.

Best Practice: Courseware should be used in appropriate instructional settings or learning environments and with appropriate audiences.

As described previously, a best practice for the design, development and use of educational courseware is a clear statement of learning objectives and goals. To be successful, these learning objectives and goals should be matched with appropriate instructional settings and learning environments as well as appropriate audiences—for no matter how good the courseware is, using it in the wrong setting will likely hinder improved learning.

Many *Premier Courseware* allow for use in multiple settings, environments and audiences, which helps potential adopters or adapters of the courseware make appropriate use of the courseware. As described previously, *Cracking Dams* can be used with three different audience levels. With *Virtual Car*, a project can be tailored to different levels of learning objectives, from simple selection of provided materials and their physical properties to more advanced listing the functional requirement of each materials to help justify the choice. Use can also be applied towards different disciplinary emphases, from "elements of mechanical engineering (performance), industrial engineering (assembly), to mathematics (spring windage calculations)"

Best Practice: The use of courseware and its impact on learning should be conducted to include appropriate stakeholders and assessment methods.

As engineering educators know from the ABET Criteria 2000, it is important to conduct evaluation and assessment on the use of any tool used in the engineering education to determine whether the desired learning objectives and goals are being met. The use of engineering courseware is no different. A challenge in evaluating the short term impact and assessing the long term impact is the development of an appropriate plan involving: appropriate learners and levels of evaluation, data collection details, and methods for analyzing the data and the results. A comprehensive plan needs participation from students and instructors, and for long term assessment possibly coordination at departmental and institutional levels.

The motivation for *Premier Courseware* development vary widely, with the following being most frequently cited: to enrich the learning experience, to enhance teaching/learning environment, to engage a diversity of learners and to provide an increase in ABET-related student's learning outcomes. To determine whether the learning experience or environments were enriched and enhanced and if learning outcomes were achieved, evaluation and assessment of the use of the courseware are necessary. Most *Premier Courseware* evaluated learning improvements by pre-/post-assessments at a minimum. Some looked at improvement in retention of underrepresented students (e.g., *Della Steam Plant Case Study, Bike Dissection*). Several included a triangulation of both qualitative and quantitative methods. For example, in *Interactive Groundwater,* the evaluations considered the whole-system learning that linked performance tasks with integrative activities, such as defining problems, making assumptions, integrating sciences, constructing arguments and articulating results. Here the assessment is an embedded, integrated and seamless part of the learning environment.

SUMMARY AND CONCLUSIONS

This paper discusses best practices in the design, development and use of engineering education courseware by examining the courseware recognized through the *Premier Award for Excellence in Engineering Education Courseware*. By reading and understanding the illustrative examples given above and drawn from the courseware recognized by the *Premier Award*, courseware developers will be able to improve their designs leading to potential increases in learning effectiveness.

In addition to the specific best practices identified in the paper, an examination of the courseware recognized by the Premier Award leads to the following general observations:

- Learning objectives, goals and assessment strategies are critical aspects of good courseware design. The best embed these features within the software itself [13].
- Case studies can be effective types of courseware—they can demonstrate real-world problems and situations requiring effective synthesis and analysis.
- Games can be effective in engaging students' attention in courseware and they can be designed to enable the learner to demonstrate his/her understanding of the material.
- Presenting comprehensive content should be accompanied by effective structure, navigation and interactivity.
- Interactive animations and simulations can be important features of courseware—they enable learners to learn in multiple ways by connecting calculations and numbers with physical representations.
- Courseware should be flexible—in the settings, audiences and objectives for which it is used so that it may be easily adopted and adapted by others.

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