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Decision criteria and change management factors in implementing instructional technology in engineering education

Jeremiah Woolsey

Concordia University
Montreal, Canada

ABSTRACT: Few would disagree that new information technologies offer substantial opportunities to improve engineering education. However, the questions to be answered involve identifying where instructional technology is warranted and where it is not. Also, what instructional problem is the technology being used to solve? For a university engineering department striving to improve the quality of instruction, it is critical to establish *criteria* in order to define the type of instructional technology objectives that will best utilise available resources and, in the end, provide the most instructional value for the university. This article provides an analysis of several instructional technology initiatives in university-level engineering faculties. Topics covered are in the areas of: *access* to knowledge, *representation* of knowledge and in knowledge *assessment.* Critical to the broad implementation of any technology project is the necessity to understand and properly address the myriad of *change management* issues that effect successful adoption. The analysis focuses on those factors that are unique to an engineering context.

INTRODUCTION

Before instructional technology can begin to be applied, the problems that are intended to be solved need to be defined. How is productivity to be measured in academia? There are a number of factors that define *faculty productivity*. In a report by California State University, faculty productivity is described as:

- Learning productivity: *the product of teaching*;
- Knowledge productivity: *the product of research*;
- Scholarly productivity: *the product of scholarship*;
- Institutional productivity: *the product of governance*;
- Social productivity: *the product of community service*;
- Professional productivity: *the product of faculty professional development, which enhances the others* [1].

The principal area within academic productivity in which instructional technology is most appropriately applied is within the domain of *learning productivity* and, to a lesser extent, in *knowledge* and *scholarly productivity*, which may be enhanced by the pedagogical knowledge produced by systematic assessments of effective practices. The author intends that this article examines how technology can improve learning productivity in engineering.

High Level Needs Analysis

In the practice of Instructional System Design (ISD), the first step towards *effective learning* is to conduct a high-level analysis of overall needs, goals and priorities. This is to be done initially at the *systems* level, hence the primary goal of the analysis was to align to the goals of the engineering department and support the department in the achievement of those goals.

The goals of a university are generally to engender critical thinking, to contribute to the body of knowledge and to impart a sense of social responsibility to its students – all noble endeavours; but difficult to measure. More empirical definitions of success are needed to be able to discern actual value. The criteria used by the government to measure success, and therefore fund the Faculty of Engineering and Computer Science at Concordia University, Montreal, Canada, is based directly on the ability to *attract*, *educate*, *retain* and *graduate* competent student-engineers. This contract calls for graduation rates in *science appliqués* to be 68.3% by 2003, 75.3% by 2007, and 82.8% by 2010. Therefore, it should be argued that the instructional technology initiatives in the Faculty are to align with these particular goals.

A University-wide pilot project was conducted over several years in order to assess the pedagogical value of instructional technology [2]. An analysis was performed on the results of this pedagogical technology project from participants in the Faculty of Engineering and Computer Science, as well as from other faculties, which provided feedback on what pedagogical benefits the participants derived from the process, and what may have hindered better results.

A post-pilot objective was to see how courseware development could be expanded beyond the early innovators to the Faculty at large. A survey was conducted to determine the following:

- Attitudes towards the value of instructional technology;
- Technical capabilities for production;
- What courseware the engineering faculty have produced;
- Obstacles that may have hindered courseware development [3].

Goal to Attract Students

More and more, the first informational contact that prospective students have is a university's Web page. From an *image* point of view, especially in programmes *of* and *about* technology, such as engineering and computer science, the projection of a technology-adept faculty gives more credence to the programme. A departmental Web page needs to engage prospective students and quickly direct them to the information they require. By streamlining the application and registration processes through online methods, educational technology, broadly defined, can contribute to *institutional productivity.*

The Student as a Consumer

University students of today are, without a doubt, a *wired* generation. In 2002, a study by the Pew Internet and American Life Project in Washington found that 86% of North American students have been online, as compared to 59% of the population at large. As consumers, students generally have quite high expectations in the use of technology in the instructional process. In a recent industrial engineering class where Web aids for the course were used, 83% of students reported that they wanted all of their other engineering courses to be similarly equipped.

A recent poll of members of the Faculty of Engineering and Computer Science (ENCS) asked what they believed were student expectations regarding Web access to their courses [3]. Of the 76 faculty members who responded (out of 152), 31 responded *high*, 39 responded *medium*, and only 8 *low*. Even with questions of the instructional efficacy of course Web aids aside, there seems to be institutional value of Web support for courses, simply in meeting consumer requirements.

Why do students seem to value Web access for their courses? Flexibility is one of the principle reasons, allowing *anytime*, *anywhere* learning to occur. The 24/7 access to material permits professors to extend class coverage. With a high number of students at Concordia working part-time, the ability to supplement in-class instruction *when* and *where* they need is highly valued. Web access also allows them a *second chance* at the material. With over 75% of the students enrolled in the Faculty having English as a second language, and an even higher percentage of Faculty staff as well, this re-processing of course material (textual, visual and aural) can be invaluable.

Typical features of course Web pages are: digital video lectures, modules that permit students to download assignments and upload when completed, and online quizzes that provide incremental self-assessment of their progress. Discussion boards allow students who might not be inclined to ask questions in class, anonymously ask for help when they have difficulty with a particular concept. Not only can the course Web sites become part of the students' institutional assessment, but so too can the quality of courseware produced, such as interactive visualisations, animations, online exercises and assessment tools.

Educate, Retain and Graduate Students

While course Web page proliferation may contribute to student perception of institutional quality and effect retention in a relatively minor way, the primary value of technology for retention is through instructional assistance and remediation. If so, then where is this technology assistance best applied? If the education process can be thought of as a system, and indeed it should be, then system *throughput* should be analysed and *defects* identified. In this case, defects are courses that consistently have high failure or dropout rates, especially in required courses. The use of instructional technology to support student retention and graduation are directed towards improving the following key aspects:

- Access to knowledge;
- Representation of knowledge;
- Assessment of knowledge.

At a more detailed level, by analysing retention rates on a course-by-course basis over time, it is possible to identify systemic *at-risk* courses. By looking at *dropout rates*, *class GPA*, and *failure rates*, it is possible to discern patterns over time that might indicate content that is consistently problematic for students. These courses, especially if they are required core courses and integral to the completion of a student's programme, are the prime targets for using instructional technology to develop Web aids, supplemental courseware, assessment mechanisms and any and all tools that can help remediate high failure rates.

For at-risk courses, at what level should the focus be undergraduate or high-level graduate courses? Analysis shows dropout percentages are highest in the first year of a programme. Also, from a *throughput* perspective, should those courses with high enrolments be targeted for technology aids?

Courseware Project Selection Criteria Revisited

The first major faculty-wide initiative to assess the pedagogical value of instructional technology at Concordia University was the Concordia-McConnell Pedagogical Technology Project. The initial criteria for the selection of projects for this pilot were based on the following aspects of a candidate:

- His/her willingness to invest a substantial amount of time and effort;
- His/her enthusiasm for the project;
- His/her experience and vision of what is to be achieved.

The criteria for initial selection were based principally on the candidate's attitude and vision. If a broader implementation and adoption is sought, how likely is the faculty at large to pursue courseware development projects? The faculty at large was surveyed to determine attitude and other factors that might hinder a wider adoption of technologies to enhance instruction.

Change Management Factors

Results from the participants in the pilot project report the two critical factors in successfully developing courseware are *commitment* and *resources*. Faculty attitude, production infrastructure, delivery infrastructure, pedagogical support, and a disciplined and managed approach were reported as factors contributing to successful courseware implementation [2].

Affective Factors

It became important to know if the faculty at large finds instructional value in technology, are willing to invest the time, and also have the required capabilities. If so, are the same criteria used for selection in McConnell met by larger numbers of faculty? Also, if there is a consensus that there is value in instructional technology, what obstacles (or perceived obstacles) have prevented a wider application? The survey was distributed to the ENCS faculty to determine these issues [3].

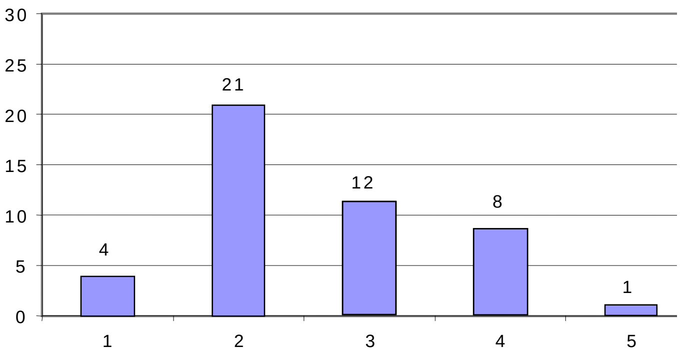
There were 76 faculty members who responded (full-time: 56; part-time: 21). Not all questions are listed here; but the results of the questions that did try to gauge attitude and capability are described below.

Faculty members were asked about the extent of student access to the Web; 55 of the 76 responded that 100% of their students have Web access, so courseware developed for the Web can be accessed by the students. As a delivery means, the Internet is a consistent and uniform method of access. It may be that we were putting the proverbial courseware cart before the horse. Why build courseware if delivery is not assured?

One of the critical questions was meant to elicit their overall appreciation for the instructional value of new media, data visualisation, and animation. *Question 2.0: Some engineering educators believe newer media and technologies such as animation and other data visualisation methods offer new and unique means for representing knowledge, and can improve the way complex abstract concepts can be conveyed. Do you?* The responses were as follows:

- Strongly Agree (26)
- Agree (44)
- Disagree (6)
- Strongly Disagree (0)

The responses demonstrate that faculty members see instructional value in these new technologies. Given that, how much has been done? If not a lot, then the question is why there is not a wider application of these methods? *Question 1.5 How have you applied newer methods or media to your delivery of course content, and if so, which? If not, then why not?* Figure 1 shows the various responses.



Note: 1 = Have not seen the need; 2 = Not enough time; 3 = Not enough background in technology; 4 = Not enough technical resources; and 5 = Other.

Figure 1: Response to Question 1.5 regarding the application of newer methods or media.

The more important question was what reasons had deterred them from developing interactive courseware. The overwhelming answer (21) was: *Not enough time*. Historically, engineering faculties are more focused on research, sometimes at the expense of teaching; however, the instructional artefacts that are produced can serve faculty members throughout their career.

The first step before one sets out to build courseware is to *review* what may have been produced so far. It is of interest in the application of new technologies to know how aware faculty members are with existing courseware in their domain.

Question 2.1 asked, *Are you familiar with new courseware development by other university faculties/consortia outside of Concordia for the type of course you teach? And if so which?* The responses were: *No* = 57; *Yes* = 24.

Although faculty members did not seem to be aware of courseware in their domain, they are open to evaluating such, as demonstrated in Question 2.4: *Are you willing to act as a reviewer of courseware offerings in your field to assess their suitability for Concordia courses?* The responses were overwhelmingly positive, with 54 saying *Yes*, and 13 saying *No*. It was apparent that it is not part of their routine pedagogical practice to review what courseware might exist for a particular course or in their domain, hence a *comprehensive courseware review* is being undertaken to locate available course content by subtopic. The focus is on finding interactive Java applets in the public domain that convey core engineering or mathematical concepts.

Overall, the survey results demonstrated a receptive attitude on the part of the faculty as to the value and use of instructional technology. Aside from the professional concerns in improving pedagogy, other incentives to engage in courseware development that were reported anecdotally were: reflection of courseware development activities in tenure review, and course remissions to free up time for development.

Delivery Infrastructure

One area of targeted improvement is in the increase in the amount of *access to knowledge*. This means in-class activity, as well as learning activity outside the classroom. Additionally, without assurance of a *smart* classroom, the incentive to create and deliver in-class media was diminished. Portable computer and projection equipment, while available, presented an added burden to administering classes. While infrastructure was intentionally not part of the pilot project at Concordia, there is no mistaking the impact of not having an established infrastructure in place.

Close to 100% of students at Concordia University have Internet access via computer laboratories, library facilities, home access or Internet cafés. If courseware is targeted for Web-delivery, it is expected that students will be able to receive courseware delivered in this medium *on-demand*, when and where needed. Instruction would not be bound to only the time and place of the lectures. Even with some of the commercially available Web course building applications, many faculty members report that the packages are too complex, require too much of an investment of time to use, and have poor performance, being very slow to respond over the Web.

A goal was to establish an accompanying Web page with minimum features of a syllabus and notes for every lecture in every course in the Faculty of Engineering and Computer Science. To speed up the process, a software package was used to build course Web pages. Workshops and one-on-one visits assisted in the adoption of this tool and the creation and maintenance of course Web pages. This course page builder software does not require the faculty member to be HTML-proficient and makes the creation and administration of course pages much easier. Over a 3-month period, approximately 85 course sites were built in ENCS. Combined with existing sites of the current 438 engineering courses, 220 have Web pages for a penetration rate of 50.2%.

Production Infrastructure

Visualisation routines and interactive graphical animations can realise new methods for the *representation of knowledge.* However, what departmental capability exists for the production of this, or even the digitisation of existing content through scanning, OCR and video? The capability for multimedia production was found to be a limiting factor.

Copyright and Intellectual Property Issues

One area that professors considered an obstacle was the use of material from previously published sources, possibly violating copyright. This also involved the protection of their intellectual property.

Estimating the Scope of Work

Overwhelmingly, participants found that the amount of work required to develop courseware modules was significantly more than had been anticipated. It is near impossible to develop the modules during the same session in which the course is being offered. Estimates to produce a couple of modules of medium complexity are from four to six months, and to be done prior to the session in which the course is offered.

Anecdotal reporting from the pilot project indicated more accurate estimates are possible in *what* it takes and *how long* it takes to build courseware. Realistically, about two to three modules of medium complexity can be produced per course session. The analysis, design, development and testing of courseware needs to be done several months prior to the start of the course. It is quite impractical to try to compress this time period or to multiply the number of modules for several reasons.

The principal activities taken up by the faculty are research and in-class teaching and it is not realistic that courseware development work be done full-time. Even with a full-time developer, the overall throughput is still dependent on incremental review and change of the modules depending on results from student interaction with the courseware that are difficult to anticipate and plan for in any detail. Supporting materials such as handouts, instructions, quizzes and grading needs to be produced in concert with the courseware. The time involved is akin to the human gestation period: it cannot be shortened and takes virtually nine months regardless. Instructional designers dedicated to specific courseware projects can improve the *front end* of the process by ensuring pedagogical soundness, by producing clear and unambiguous specifications for programmers, by programming themselves or producing multimedia artefacts.

Systematic versus *Ad Hoc* Courseware Development Process

Most of the individual initiatives under the pilot project were done *ad hoc*, building and improvising as they went. While they were subject matter experts, upon going into the project, faculty members generally did not have extensive experience with the courseware development process. Comments from pilot project participants sought a more systematic and disciplined approach with more rigorous project management practices to be applied. As stated previously, the roles and responsibilities of those involved need to be clearly defined and delineated. With a rollout to the faculty at large and anticipated deployment of larger numbers of courseware projects, a systematic documented approach is even more critical to effectively plan, track and manage resources.

The process of courseware development that had been undertaken was comprised of mostly individual, disconnected efforts with varied results. Many times, the development process was done informally, consisting of conversations with the programmers. If, for some reason, either party were to be unavailable, the work could not effectively proceed. At times, the approaches were improvised and refined as the process progressed. Feedback from pilot project participants requested a better method in order to track developmental activities.

A well-defined *Courseware Development Process* can help ensure timely and effective modules [4]. An established methodology and framework can define certain roles and responsibilities, let participants know what is expected of them and when, and can provide a uniform and consistent set of *best practices* and standard design specifications. This methodology should allow for the sharing of common tools and resources, to develop modules with re-use and for re-use. A standardised process would enable the redeployment of resources, and not have the projects be limited to the schedule and availability of specific individuals. Courseware documentation would assist in the software maintenance as well. Evidence from some post-McConnell projects indicate the number of iterations from programmers, hence development time was reduced by use of standard storyboarding templates.

It is recommended that any courseware methodology be based on the Instructional Systems Design (ISD) ADDIE model: Analysis, Design, Development, Implementation and Evaluation. The ADDIE model is an iterative process, modified as various phases are evaluated. The end product of one phase is the starting product of the next phase. This process can be turned into an actual workflow system whereby ISD elements are captured through templates in Web-based forms. This is further described in Table 1.

Class Management Revisited

With the implementation of Web technologies, the use of classroom time seems to be undergoing re-evaluation. While the access to knowledge grows, there are downsides. Some instructors report that if they put all the course material on the Web, they risk students not coming to class and missing more detailed information, valuable discussions, the chance for questions and the exchange of ideas. Instructors recommend using the course Web pages to present some information and exercises, but not all, and to use class time more for review.

In-class wireless connections to the Web can also provide new opportunities for potential distractions. The new technology poses a challenge for professors to retain their students' attention. When going into a wireless classroom, one is likely to see as many students surfing or playing the myriad of games as reviewing class content.

Courseware Quality: Instructional Efficacy

At the courseware level, particularly for visualisation and algorithm animation, there are pedagogical elements that have shown in research to be effective and should guide design considerations [5][6]. These include the following:

- General purpose systems: common interfaces offer easier integration of animation visualisations into a course.
- Input generators: students should be able to provide inputs to an algorithm.
- Rewind capability: this is effective to aid understanding student needs by being able to backtrack.
- Structural view: this allows jumping to key points.
- Interactive prediction: actual visualisation must be stoppable with stop-and-think questions to engage.
- Database support: the ability to capture quiz-for-real data to evaluate students and evaluate efficacy.
- Inclusion of hypertext: system support integration of explanatory hypertext.
- Smooth motion: this helps users to detect changes between successive steps.

Table 1: Phases, tasks and outputs of the ADDIE model.

Phases	Tasks	Outputs
Analysis Process of defining <u>*what*</u> is to be learned	Needs assessment Problem identification Task analysis	Learner profile Description of constraints Needs, problem statement Task analysis
Design Process of specifying <u>*how*</u> it is to be learned	Write learning objectives Develop test items Plan delivery method Standards applicability Identify resource requirements	Measurable objectives Instructional strategy Storyboard & script Functional design specifications
Development Process of authoring and producing the courseware	Review with instructor and designer Program courseware Program exercises	Structured & commented code System requirements User documentation Implementation plan
Implementation Process of installing and using the courseware in the actual context	Instructor training Run through with small group	Student feedback Error & bug reports User interface comments Usage data
Evaluation Process of determining the adequacy of the instructional module	Time measurement Interpret test results Poll graduates	Recommendations Project report Revision or addition of courseware modules

SUMMARY: TOWARDS AN INTEGRATED ENGINEERING CURRICULUM

The initial pedagogy and technology pilot project has played a critical role in raising awareness in the Faculty of Engineering and Computer Science as to what is possible given new technologies. It has also challenged virtually all members to reassess their pedagogical practices.

In actuality, courses are not standalone, isolated *islands* of content and knowledge. They have multiple cognitive entry points and exit points, owing to prerequisite knowledge and coursework, hopefully progressing to subsequent higher-level more complex, advanced concepts. It is hoped that through this development process, meta-data about these courseware modules is captured that helps to define the relationships between modules, both within the course or external to the course. With basic pedagogical meta-data captured, a digital repository of courseware modules can be built to facilitate the development, re-use, dissemination and maintenance of instructional objects and modules.

In order to derive the full pedagogical benefit of courseware, it is important that the design stage take into account the possible re-use by others in a particular domain. Therefore, metadata should be defined in order to allow the creation of standard XML-based (IEEE-LTSC) engineering domain repositories [7][8]. This will enable searches and queries on instructional modules by others in the field. Massachusetts Institute of Technology (MIT) has begun the *Open Courseware Initiative* wherein their 2,000 courses will be available online in the public domain [9]. There are a good many Java applet courseware modules that already exist in the public domain. Indeed, before engaging in the development of courseware modules, a Web review of existing courseware should occur.

Using W3C standards to define learning objects, a digital library of engineering courseware modules could serve as a data exchange centre for engineering and computer science faculties. Given a standard vocabulary for engineering learning objects, it is possible to integrate with engineering curricula, thereby allowing different engineering faculties in the international community to contribute to, and draw from, the pedagogical body of knowledge in engineering education.

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Conference Proceedings of the
6th UICEE Annual Conference on Engineering Education
under the theme: *Educating for the Right Environment*

edited by Zenon J. Pudlowski

The *6th UICEE Annual Conference on Engineering Education*, under the theme of *Educating for the Right Environment,* was organised by the UNESCO International Centre for Engineering Education (UICEE) and was held in Cairns, Australia, between 10 and 14 February 2003. This 6th Annual Conference of the UICEE was an academic activity that, basically, commenced the 10th year of the UICEE's operations.

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- Case studies
- Specific engineering education programmes
- Course development in engineering education

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