Longitudinal Evaluation of Innovative Technology Based Curricula: Integrating the Learning of Mathematics with Applied Science and Engineering

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The role of technology as a support to instruction and curriculum is now a major concern of higher education faculty. An increasing number of students and instructors are using technology both in and out of traditional classroom settings. As these changes are being integrated and implemented, developers and evaluators are being asked to provide evidence of successful teaching and learning. The few evaluation efforts to date have focused primarily on documenting long term outcomes assessed by standard testing methods, however very little effort has been made to establish valid ways of improving design and use as it occurs. An additional area of concern arises from the use of technology to support curriculum when there is a lack of knowledge of impact on students' cognitive schemas. This paper presents the findings of a five-year project, known as Project Links,[1] conducted at Rensselaer Polytechnic Institute, funded under the National Science Foundation initiative Mathematics Across the Curriculum. As part of this grant, 33 interactive technology-supported curriculum modules were developed that integrated mathematics into the disciplines and practices of applied science and engineering.

The theory of information processing, or how "we convert information from stimuli into interpretation of what we are perceiving and what it means"[2] served as the underlying model of cognitive psychology for this evaluation. The model focuses on the internal process that intervenes between the content to be learned and the student's selective memory of learning. Related to this model is the concept of instructional scaffolding. This refers to the process of controlling task elements that are beyond the learners' capabilities so that they can focus on and master those features of the task that they can grasp quickly[3]. As Vygotsky theorized, the learner's interactions with the environment of learning contributes to success, and the experiences that one brings to learning greatly influence the outcomes of learning[4]. Consequently, learning is affected by both the individual and the method of instruction. For instance, the learning performance of an individual is likely to be affected by the interaction between cognitive style and the way the instructional material is structured, the mode of presentation, and its type of content[5]. Computer supported learning and instruction should also be impacted by these variables. That is, the students' ability to use and learn from technology-supported curriculum modules should reflect the degree of collaborative learning and problem solving found in the module that is applicable to their perception of the world; learners with varied cognitive styles will use instructional information in different ways; and instructional environment, even when computer controlled, will impact students' perceptions of learning and their motivation to learn more.

Purpose of the Paper

The purpose of this paper is to present the methodology and findings pertaining to a five year NSF-funded project that developed innovative technology-based curriculum integrating principles of learning mathematics with applied science and engineering. The specific focus of the paper will be the methods developed by the project's staff and the evaluators that documented the validity, usability, and relevance of the curriculum packages.

The Development of Curriculum Units and the Role of Evaluation

The major goal of Project Links was to create a library of interactive multimedia hypertext modules that link abstract mathematical constructs with their practical real life applications in engineering and the sciences. More specifically, the modules were to serve as instructional tools which could be incorporated into course curriculum to help students remove the artificial barriers making it difficult for them to integrate mathematics with science and engineering. This goal was reflected in the following project objectives:

- To stimulate greater cooperation among faculty in the discipline areas of mathematics, science, and engineering through the development of computerized instructional modules which would be appropriate for use across all three disciplines,
- To encourage higher education instructional faculty to produce and integrate more interactive teaching and learning strategies into their course curricula,
- To create a library of technology-based instructional modules that would link topics and concepts in mathematics to content typically studied by science and engineering students, with direct application to the field of practice.

The majority of the technology-supported curriculum modules created under Project Links were designed to be used during the first two years of undergraduate study. The content of the modules focuses on the topics and materials typically covered in mathematics, sciences, and engineering courses with large enrollment numbers. Following is a list of the major assumptions underlying the design, development, and evaluation of the modules:

- Modules would be written at the appropriate instructional level for grades 13-15 and would encourage student interaction during usage of higher-level problem solving skills.
- Modules would include embedded instructional information to assist instructors with the integration and implementation into current curriculum.
- Mentors and instructors would be adequately trained in the use of the modules and in their integration, but this training would not be time-consuming nor would it require special skills or equipment.
- Modules would be adaptable to a variety of instructional settings depending on the individual instructor's preference and needs.
- One or more instructors would be available during student usage. The modules are not to replace the role of the instructor in the classroom; rather they are to facilitate teaching and learning.

- Modules would encourage students to work in collaborative and/or cooperative groups while in the classroom setting.

The specific method adopted by project staff was the development of computerized web-based modules that could be used by faculty and students as adjuncts to classroom instruction, facilitating the review of old material and the instruction and learning of new principles. To facilitate this process, teams of faculty representing the disciplines of mathematics, engineering, science, technology design, and instructional design cooperatively determined content of the modules and jointly developed and reviewed the modules.

Evaluation Methodology

As part of the evaluation effort for this project, a multi-phase longitudinal evaluation plan was designed to assist in developing and validating the usability and relevance of the curriculum modules. Five phases of evaluation were developed and used, in a cyclical method, for each module. The first phase consisted of a review of the module content; the purpose of this review was to provide outside, expert validation of the accuracy and relevance of the information conveyed by the module. This included a review of mathematical as well as application content and theory. Although the authors of each module were selected based on their expertise in content and teaching, project staff deemed that a review of content, similar to that undergone by quality texts and published theoretical works, would allow for greater generalization of the modules across disciplines and institutions. As a result, a minimum of two external reviewers were solicited for each module wherever possible: one representing the viewpoint of mathematics, the second that of the content or applied area of integration. To facilitate these reviews a standard form was developed and made available for use either in paper or electronic format. Specific domains covered by these reviews included: 1) importance and relevance of the module's instructional objectives, 2) the accuracy of the content, both applied and mathematical, 3) the use of real life applications, both applied and mathematical, 4) the level of difficulty and the appropriateness of material for undergraduate learning, 5) the integration of learning across disciplines and the relevance of the module in facilitating inquiry-based learning, 6) appropriate presentation of facts and aids in a manner that facilitates instruction and learning. Results of these reviews were provided to the module developers, project staff, and the technical manager for editing purposes. Where appropriate, follow-up reviews also were solicited.

The second phase of evaluation consisted of a user interface and educational technology review by experts in the instructional technology area. Again, a standard form was developed that would allow external reviewers who were specialists in instructional design and technology to review and rate each module in terms of its ability to provide content according to state of the art practices in technology integrated instruction. This specialized form integrated the objectives of each module along with the objectives of the project to assess the relevance of the presentation of material and the flow of instruction and learning. This included but was not limited to: learner orientation, use of a pedagogical framework, learner control of the process, the quality of feedback, the inclusion of motivating devices, spaces for practice and interaction, student-centered management of learning, and documentation of student learning. Additional variables included presence or absence of culture and gender bias, usability by those with varied learning styles, and appropriateness of supporting materials. Findings from these reviews were summarized and provided to the project staff, development teams, and technical staff to assist in formative editing. In general, each module received at least two sets of reviews, with earlier reviews focusing more on the process of using technology to deliver instruction and later reviews emphasizing the instructional relevance of material. It was noted that as technical staff and module developers became more familiar with the process of instructional design, modules developed in the last two years of the project were initiated with many of the needed instructional devices, thus allowing for more in-depth feedback at earlier stages of design.

The final three phases of evaluation addressed the usability of the curriculum modules by diverse audiences in diverse settings. The usability evaluation (phase three) evaluated each module for relevance across different learning styles and levels of student experience. In this phase, individual learners utilized the module in contained lab-like settings where they were directly observed by an evaluator while completing the curriculum unit. Four types of learners were involved in this process; those who were novice or expert in the content area and those were novice or expert in the use of the technology. At the initiation of the module use, participating students also were given a learning style inventory that allowed for assessment of global and sequential patterns of thinking. In addition to being observed in the use of the module, participants were encouraged to "think aloud" as they went through the module. This progression through the module, along with the think aloud comments, was videotaped and used to determine sequences and patterns of module use by the types of learners and the ability of the module to be effective for varied types of learners.

The fourth phase of evaluation involved direct observation of early module use in "real-time" classrooms. The purpose of this phase of evaluation was to provide project staff with formative feedback on the general utility of the curriculum units in multiple classroom settings, and areas in general module development that were in need of assistance or further refinement. To fulfill this requirement, evaluation of direct use of modules in varied classroom settings was conducted throughout the year. In general, 15 to 20 classroom uses per year were documented; this included observation of the use of the module, surveys of students, interviews with randomly-selected students, and follow-up interviews with instructional staff and developers. A total of 1,548 student surveys were collected over the five-year grant cycle. Variables assessed on the part of the students included perceptions of the module content, the instructor, the format and setting of the module use, the relevance of supplementary instructional materials, and the effects of module integration on student learning. In addition, students were asked to indicate their perceptions of the impact of computerized learning on their overall learning and areas where they perceived module refinements should be considered. Observation and interview variables confirmed these points, but also documented student and instructor perceptions of the ability of the modules to meet varied instructional settings and levels of student use. Data from these "real-time" classroom room observations provided formative feedback on the benefits of additional paper-pencil resources, the validation of assumptions (especially those related to need for active instructor presence), and the ability of the modules to assist in cooperative, inquiry-based learning. In all cases, data for phase four were aggregated across classrooms as a means of controlling for instructor variations.

The fifth and final phase of evaluation documented the ability of the curriculum modules to meet the needs of varied instructional settings. This phase utilized data collected over the entirety of the five-year cycle and allowed for comparison of module use across instructional settings. Over the course of the five years, 7 of the 30 modules were utilized across multiple settings or instructors in manners that allowed for cross-sectional, longitudinal analysis of usefulness. One of the modules was used in 11 different classrooms by 7 instructors during one semester, one module was used multiple times over the five years by the same instructor in three different instructional settings (lecture, in-class, and studio classroom), three modules were used in lab and studio settings, and two modules were used progressively as lecture, in-class work, and homework aides. Variables examined in this stage of evaluation included student perceptions of relevance, impact on learning, relevance to classroom learning, and transferability of knowledge. Findings from these sub-studies provided final summative documentation of the modules' use and relevance in different instructional settings for varied students and instructors.

Summary of Findings

Multiple findings resulted from this longitudinal evaluation of the design, and the development and use of curriculum modules. Four of these findings pertain to the process of designing and evaluating technology-based curriculum for students in engineering settings, and four pertain to the impact of use of the modules in applied settings. Following is a summary of the major findings.

Designing and evaluating technology-based curriculum. This project resulted in a demonstrated, effective means of designing, developing, and assessing technology-based curriculum in the math, science, and engineering fields. The use of multi-disciplinary based teams, coordinated by project staff and assisted by technical assistants, proved an effective method of ensuring curriculum that could and would be used by faculty and student in discipline-based and cross discipline-based learning settings. As this model was developed and refined over the life of the project, it was noted that greater emphasis was put on the co-creation of student-centered "real life" learning, with a greater understanding of all team members of not only the content and the application of the content but also on methods that would facilitate inquiry-based, collaborative learning reflective of higher level career patterns. Within this multi-stage cyclical model for developing curriculum, several components were noted as key to the development of sound instructional modules. These included the following:

- Need for content and instructional design/technology reviews. The use of standardized content and instructional design/technology reviews were seen as fundamental to the process of developing validated curriculum. The information provided by outside reviewers allowed developers and project staff to design material that would interface with multiple classrooms and modes of instruction with confidence in the use of content and applications. These reviews also provided evidence that the material was not "individual instructor" based but was, in fact, intra and interdisciplinary based. In addition, the standardized form of these reviews allowed for comparison and design improvement across multiple modules at the same time.
- Need for evaluation of "real time" use. The use of "real time" evaluation proved to be a major component of evaluation for this project both in terms of documenting the effectiveness of anticipated variables and finding unanticipated outcomes. Through the consistent use of cross-sectional and longitudinal observations in real classroom settings, the evaluators and project staff were able to document technology, design, and

instructional variations that impacted learning by students. For instance, it was through the observation of use in real classes and the subsequent interviews with students and faculty that findings pertaining to the positive use of in-class hands-on assignments that blended and reinforced lecture and applied problem solving were noted. As a result of these finding during the initial use of modules, subsequent module designs automatically included this technique. Additionally, it was through observation and interviews with students who used the modules in real class settings that disparities between module work and graded instruction were noted. Other findings noted or supported by the use of "real time" evaluation included limits to variations in instructional settings, instructional style, and class cultures that could be supported by the modules.

- Need to address student and instructional variables in evaluation. The use of usability studies, controlled observations, video taping and think-aloud techniques as part of the design and evaluation process allowed for study and adaptation of the modules in ways that would support their use by students with varied backgrounds in terms of learning styles, expertise with content, and expertise with technology. The direct observation of individual students in controlled settings allowed the evaluators to document the need for designs that would support both global and sequential learners. Early designs of modules were generally linear in nature, meeting the needs of sequential or inexperienced content learners; however, reviews of patterns of interactions noted that experienced content users, especially those with experience in technology, and global learners no matter what their experience level, soon became bored or frustrated with lock-step learning. As a result, the instructional designs of the modules were refined to allow for both linear and searching techniques that would accommodate multiple types of users. Additional findings over the course of curriculum development indicated that female users perceived the motivation of the modules and their subsequent impact differently than did male users. As a result instructors were able to accommodate varied individual needs of students.
- Need for continuous cyclical formative evaluation. The provision of formative, cyclical evaluation, on all parts of design and development allowed for the refinement of both the process and the products created under this program. Early formative evaluation not only to allowed for correction of specific modules but also altered the general design of the module and subsequent development for all modules. As this process continued, the evaluation was able in latter stages of curriculum development to focus more on the product and less on the process, thus becoming part of the development process itself. It also was noted that a joint learning process was supported by the cyclical, formative nature with project staff who were technically oriented becoming more adept at content and instructional practices, while team members who were instructional or support in nature became more adept at content and the interdisciplinary aspects of curriculum design. This movement toward a shared understanding of curriculum and instruction facilitated the development of more broad based units of instruction that were viewed as serving the needs of more instructional settings.

<u>Use of technology based applied curriculum.</u> Several findings of this project also provide direct evidence supporting the process and impact of using technology-based, applied curriculum in undergraduate math, science, and engineering classes. Overall, the process of integrating technology-supported material into the curriculum proved to be successful; students and faculty

reported more motivation for learning, more desire for real-life problem solving, and more ability at real life decision making within the students' discipline. In addition, it was noted by faculty that students had a broader view of the need for mathematics within the sciences and engineering and were more adept at transferring knowledge. When the material was applied directly to course content, either via studio-based hands-on learning or instructor-supported lab/homework settings, students perceived a greater relevance of the content and its need for the practical settings. The use of computerized settings was noted to allow instructors to adapt transfer of knowledge to meet the individual variations of students and limitations of instructional settings. Specific findings pertaining to the use of technology-supported curriculum in the classroom include the following:

- Impact of learning style. This study supports the importance of acknowledging student learning style when designing curriculum for undergraduate students. Evidence indicated that use of technology may either positively assist or negatively aggravate the impact of an individual's method of cognitive construction. Students who are global or constructivist in nature are frustrated easily by linear technology-based instructional design and will frequently cease attempting to develop the cognitive structures necessary for task completion. In this project, however, it was shown that curricula can be designed to meet the needs of either global or sequential learners.
- Impact of level of experience with technology and content. Classroom students' background in both the content covered by the curriculum material and with the use of the specific mode of instruction interacted to impact perceptions of the relevance and usability of the modules. Those students who were novices in material and in technology tended to prefer a linear method of learning and navigation through modules. Students who were more experienced in both the content and the use of technology-supported learning had greater need for searching and seeking. Clear patterns of progression through the modules were noted for these variations in learner background, and in cases where the module did not allow for individual pattern development student frustration was reported to be high. For those users who had a high need to search and seek, the lack of this ability, with the enforced need to progress in a linear pattern, frequently led to early termination of the modules without successful completion. This need for pattern searching has implications for future development of technology-supported instructional modules, indicating that either the type of learner must be more clearly identified by the developer or methods of pattern matching must be included in the design.
- Importance of student gender when studying cognitive growth. The findings of this study reinforce the need to continue the inclusion of gender when studying cognition and motivation in the math, science, and engineering fields. Gender differences in the affective domain were noted when studying the impact of the technology supported curriculum modules. Females self reported a lower level of confidence in their ability to learn material at the undergraduate level in math and science classes prior to use of the modules than did male students. After completion of the modules, however, female students self-reported higher levels of confidence in ability to problem solve, relevance of material, and motivation for learning than did male students. Female students also responded more positively to collaborative/cooperative learning methods than did male students and perceived interaction with peers and/or team members to be more facilitative toward project completion than did male students. The direct effect of the computerized modules on this process is not conclusive; however, the finding does suggest that the use

of computerized aides to learning, especially those using collaborative learning, may facilitate female students' motivation for continued work in math, science, and engineering. Certainly further efforts to study the relationship of student gender to perceived effectiveness of learning is warranted.

- Adaptability to varied instructional settings. The findings of this study also provide implications of the use of technology-supported curriculum in varied instructional settings. Although the underlying assumption for development of these modules was that the instructor would be present to assist in learning, it was noted that the curriculum could be adapted with some care to other instructional environments. This included self-sustained review sessions, stand-alone homework assignments, and instructor-guided lab settings. What is not clearly documented, however, is the impact of the use of technology-supported modules on long-term problem solving. While it was evident that students expressed similar levels of relevance of material and motivation to use the content despite variations in instructional use, no attempts were made to document long term relevance, sustained motivation, or transferability of knowledge to other instructional settings.

The findings of this project have clear implications for the continued support of technology-supported curriculum. The project created, tested, and refined a method of developing validated curriculum that impacted students' cognitive and affective domains. Further work in curriculum design should replicated and adapt these methods to other disciplines and continue to study the impact of student and instructional environment variables in use.

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