

Content and Delivery: the NEEDS Infrastructure for Distance-Independent Education in Synthesis¹

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The Synthesis Engineering Education Coalition strives to integrate multidisciplinary, open-ended problem solving into the varied engineering curricula of its members. To achieve this goal, Synthesis has developed a broad array of computer-based multimedia courseware elements. In addition to the courseware, Synthesis has developed NEEDS, the National Engineering Education Delivery System, as the infrastructure for disseminating these and other education materials over the internet. Some interesting challenges have been identified through this effort: How can electronic courseware meet the diverse needs of curricula among a cross section of universities? How do educators adapt traditional teaching roles to fit new resources and delivery styles? What courseware access modes equally suit the needs of author, teacher, and student? Can an infrastructure designed for static courseware be adapted to dynamically changing information on the World Wide Web? The experience of Synthesis/NEEDS can begin to answer these questions while opening more issues in distance-independent education.

1. Introduction

Synthesis is a coalition of eight diverse campuses² united to effect a positive change in engineering education through the integration of multidisciplinary, open-ended problem solving into the current curriculum. The members of Synthesis span broad distances not only geographically, but also in their educational missions. Supported by the National Science Foundation, the coalition is united through a common commitment to developing and delivering computer-based instructional modules (courseware) to augment the traditional curriculum with 'Synthesis-rich' material.

NEEDS is the prototype information server designed within Synthesis for the delivery of courseware to the educational community. Based on the library model for resource

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identification and access, NEEDS provides the infrastructure to distribute electronic course materials both through direct catalog queries and through contextual browsing. Multimedia courseware modules represent a substantial resource from several standpoints: providing media-rich course material that is difficult to communicate in a traditional classroom setting, serving as a basis for local customization of courseware to fit into varying curricular needs, and supporting student exploration through modularization of information topics. NEEDS provides multiple interacting access modes to courseware to meet the varied demands of its user community of author, teacher, and student.

By extending the NEEDS infrastructure to include group communication, we can breath life into static courseware material with dynamic discussions among students, teachers, and perhaps domain experts. Additional network discussion areas can focus on feeding back useful pedagogical experience to the authors and users of modules, promoting their growth and extension in response to the learning needs of various student groups. Through its deployment on the World-Wide-Web (WWW), NEEDS can both contribute to and exploit the web as a learning resource.

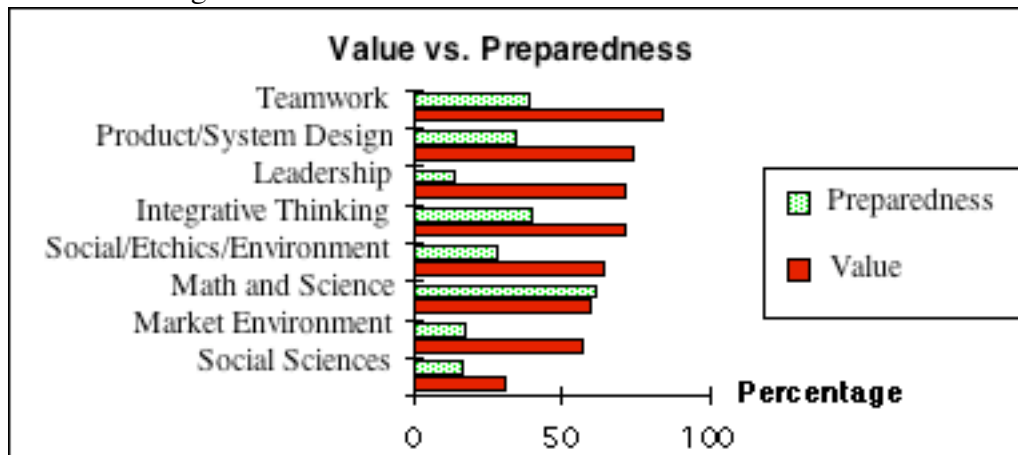


Figure 1. Results of NSPE survey assessing key skills of engineering school graduates.

2. Synthesis: Supporting Curricular Change

Synthesis is dedicated to the improvement of engineering education using specific criticisms of the preparedness in several key areas of engineering graduates to direct the effort. Figure 1 tabulates desired vs. perceived performance in a survey of industry performed by the National Society of Professional Engineers [1992]. From this and other studies, Synthesis has developed the following emphases:

1. **Synthesis Interdisciplinary Content:** Engineering curricula must expose students to creative, cross disciplinary synthesizing and open-ended problem formulation and solving. The engineering process
2. **Concurrent Engineering and Industry Practice:** Emphasize concurrent engineering and life-cycle design. Include team building and group experiences to foment interdisciplinary understanding. Bring industry into the classroom through involvement in Synthesis projects and multimedia engineering design case studies.
3. **Laboratory/Hands-On Experience:** Teamwork, experimental design, and the integration of phenomenological theory with actual system behavior must be stressed. In the laboratory the computer is key to controlling experiments and providing data acquisition, system modeling, and data analysis.
4. **Communication and Social Context:** Engineering is a social activity. Decision-makers must understand the social implications and context of technology. Multidisciplinary teams, customers, and vendors must communicate effectively for successful product realization. Synthesis-based curricula hone students' written, verbal, and graphical communication skills and stress the ethnic and cultural diversity essential in today's world.

Synthesis has taken a leadership role in the development of high technology, computer based engineering courseware. We have taken a realistic view of the opportunities available for improving engineering education within its current curriculum framework. Efforts at curricular reform across the coalition have identified the existence of substantial institutional roadblocks to gross changes in the way engineering education is carried out. While there has been a great variation among the participating schools in the degree to which their engineering curriculum could be altered to suit Synthesis goals, wholesale changes in methodology are unwelcome.

The most effective road toward the curricular change within Synthesis has been to add elective courses which stress coalition goals and to develop Synthesis-rich courseware to augment the current engineering track. The overall scheme is demonstrated in Figure 2 where the traditional curriculum, characterized by discrete 'blocks' of knowledge, is cemented through the introduction of 'Synthesizing' courseware.

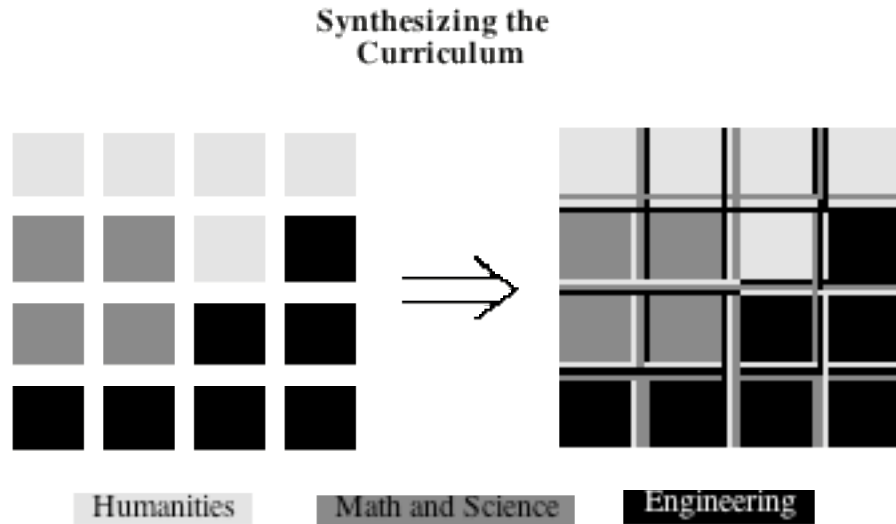


Figure 2. Synthesis courseware weaves together discrete knowledge patches into a unified integration of engineering knowledge by stressing industrial practice, social context, and multidisciplinary design.

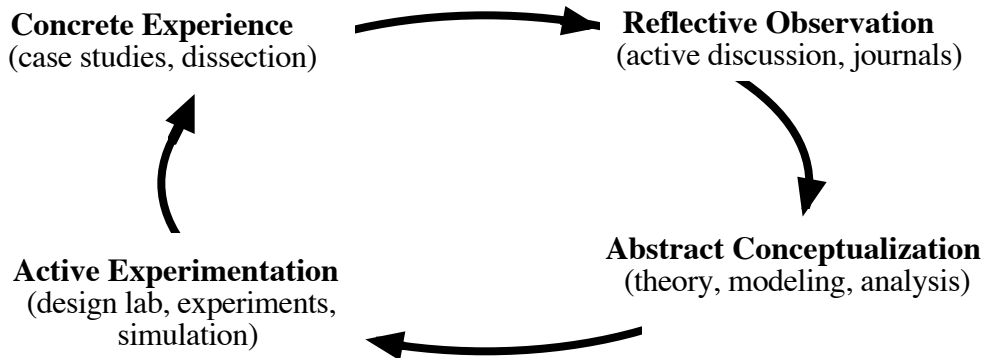


Figure 3. The Kolb model for learning annotated with courseware type designations for each aspect of the experiential learning cycle.

3. Synthesis: Courseware to Support Learning

In an undertaking as large and diverse as Synthesis, it has been necessary to have an overall guide for learning so that the role of the student in the learning process is not overlooked. The model of learning most appropriate to our goals is described by Kolb [1984] as consisting of four main components: reflective observation, active experimentation, concrete experience, and abstract conceptualization. This cycle of learning is shown in Figure 3 with examples of courseware content or activities appropriate to each learning component. By focusing on the student and recognizing that no single component of learning is adequate by itself, a . Synthesis courseware falls into some general classifications:

Case Studies of design projects from industry highlight 'best practices' including strategies for solving open-ended problems. Specific topics include team building, life cycle design, social context for design, and organizational aspects of engineering.

Lab Guides use computers to integrate lab handouts with the collection, analysis, and display of data. Mathematical theory is enriched with experience by linking together math solvers, data collection, and analysis facilities.

Concept Modules teach specific engineering concepts and are useful where visualization is an important aspect. For example, dynamic systems are simulated for better visualization of theoretical concepts; dam inspection courseware couples analytical information to strong visual clues provided by real-world images.

This list is not meant to exclude other courseware types but to indicate the main emphases within Synthesis. With its ability to make courseware 'come alive', multimedia plays an important role as the primary format for courseware in NEEDS. Connecting together presentations that integrate text, video, sound, and analysis or simulation software has proven quite effective in communicating courseware content [Hsi and Agogino, 1994] in a computerized format. Regardless of courseware format, a combination of activities is encouraged in support of varied learning styles. Small quizzes are used as a check on basic comprehension and to underscore significant points for review. Open ended questions are posed to encourage the application of the major lessons. Traditional exercise problems are also given. A teacher's guide to the use of courseware is included in software archives. While the challenge in NEEDS is to support effective access to courseware modules in hypermedia format, on-line access to more traditional course materials is not compromised.

The main goal for NEEDS is to facilitate this revolutionary and continuing change in the classroom. NEEDS must support the storage and dissemination of the general content of the engineering curriculum along with Synthesis improvements that address known shortcomings of this curriculum in a framework that enhances the ability of a student to apply experiential learning techniques. It must act as a shared resource across the entire engineering education community to rapidly transfer these new technologies into the national curriculum. Experience has taught us that a modular approach to courseware development is the only way for this material to be useful across even as small a group of institutions as that embodied by Synthesis. Courseware modules within NEEDS are thus

designed for ease of revision and effective reuse in a wide range of settings, including classrooms, laboratories, and other student environments. In addition, this courseware must be designed to encourage active learning and accommodate different learning styles among a diverse student population. Thus the imperative is on an information system that can satisfy these diverse goals, NEEDS has evolved into an effective tool from the multiple viewpoints of all of its users.

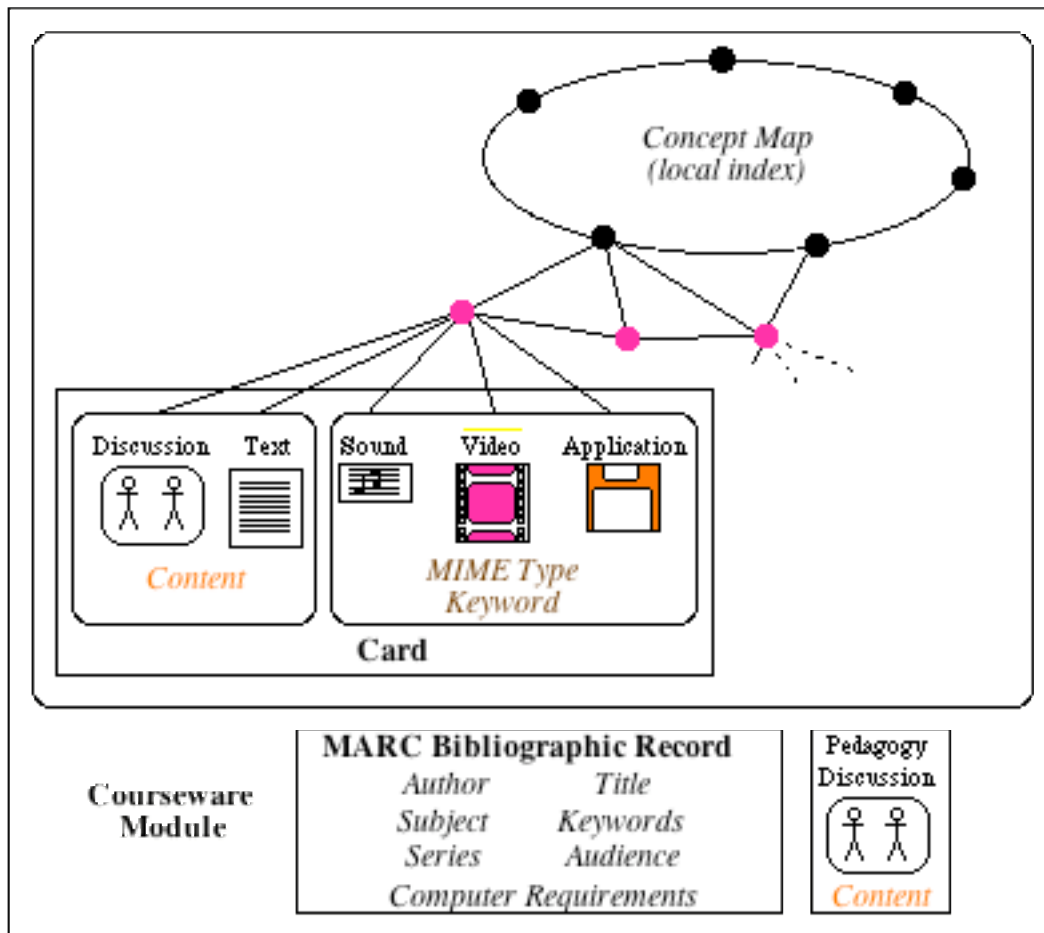


Figure 4. Courseware is cataloged in MARC format and indexed along standard library practice. Courseware elements are indexed according to their MIME type (media format and file specification). All textual material is indexed using a WAIS content database.

4. NEEDS: Serving Courseware Modules

NEEDS employs a central database that stores and indexes records which can be transferred in the library standard format, USMARC. A virtual library whose 'stacks' are computer archives distributed throughout the internet, NEEDS provides resource access in the library idiom. In the physical library, the catalog search is just the beginning of a

process that can also include browsing among the library stacks near the initial catalog 'hit'. This strategy is a good one because library resources are organized conceptually according to cataloger assigned classifications. Digital archives do not offer the same organizational structure; ironically, resources available to anyone on the network suffer from isolation that is not a problem in physical libraries.

NEEDS replaces the library 'shelf' with many virtual 'shelves' found by hypertext links from the typical MARC record display resulting from the initial query. As indicated in Figure 4, courseware is indexed along several axes: author, title, subject heading, keywords, series, audience, and computer requirements. Relevant resources identified in the initial catalog search suggest browsing paths along their assigned subject headings and among other elements of a courseware series because these search modes are automatically included as part of the catalog record display. Links to courseware author, discussion groups about how to use the courseware, and evaluations can also be embedded in the catalog record. In addition, the NEEDS infrastructure provides all of the normal advantages ascribed to digital libraries: immediate access to the requested resource, perpetual availability through duplication of electronic material, removal of temporal and spatial constraints.

5. NEEDS: Access to Courseware Elements

While the library model applies to 'substantial' pieces of courseware for which the effort required to create and catalog rigorous surrogate records is justifiable, there reaches a level of courseware granularity at which storage and indexing this way is economically unwise. In addition, the bibliographic search itself tends to imbue items so cataloged with some level of importance. The system should not mislead the user about the completeness of a piece of courseware or clutter the results of a search with items of an incomplete nature. For this reason, a second catalog is maintained for access to the constitutive components of educational courseware shown as cards, sound, video, and applications in Figure 4.

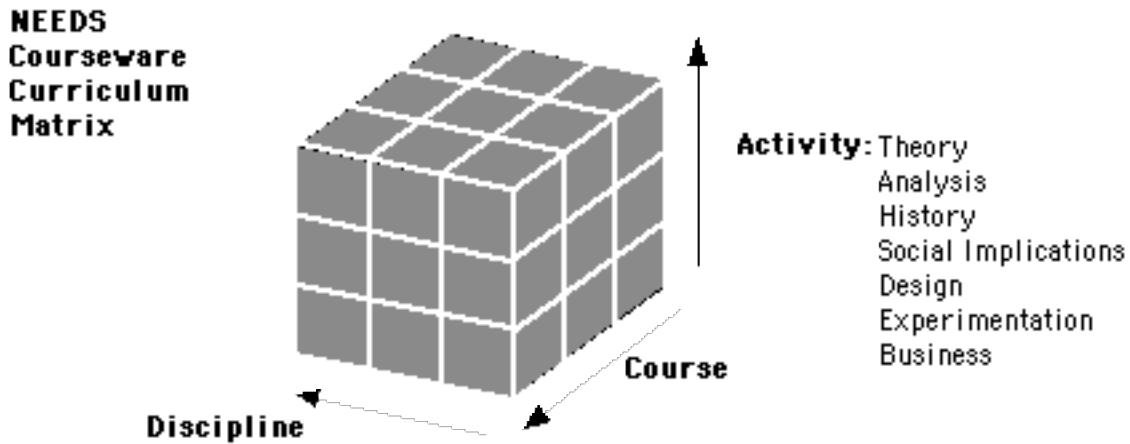


Figure 5. The Courseware-Curriculum matrix shows how components of courseware modules can be used as building blocks for new courseware.

This second catalog allows developers to identify and reuse aspects of stored courseware, adapting these elements to their own pedagogical needs. Courseware elements are the constitutive quanta of courseware modules and include information and activities in a variety of media. Within Synthesis, courseware modules are designed such that interesting elements can be distilled from several modules and joined together to create new customized modules. Viewed as a three dimensional matrix identified by activity, discipline, and course level, the courseware-curriculum matrix shown in Figure 5 provides a good model for overall indexing goals. Each courseware element is thought of as residing at a particular point in the matrix. There exist arbitrarily many ‘curriculum paths’ through the courseware curriculum matrix, some of them already mapped by existing courseware modules, others to be assembled ad hoc in response to specific teaching goals or user interest. This is the purpose of the secondary catalog to provide access to components of courseware, minimizing the need to redevelop expensive multimedia elements for new courseware applications.

Several levels of granularity exist within a hypermedia courseware module. Figure 4 shows a module comprised of several topics which themselves might be decomposed further into cards and elements until distinct concepts are represented in a variety of media. For large courseware modules, controlled vocabularies such as the Library of Congress Subject Headings, INSPEC, and the Engineering Index are appropriate for representing the content. Courseware elements require more detailed indexing than is readily available. Thus, the secondary catalog relies heavily on user generated keywords for indexing based loosely on the axes presented for the courseware curriculum matrix of Figure 5. Authority for adding

keywords is restricted to an administrative cataloger with whom authors must negotiate to extend the indexing vocabulary. Additional indices associated with the media type of the courseware element (i.e. html page, text, image, video, sound, application, etc.) are based on the MIME standard. Cataloging is performed by the author with little supervision required.

6. NEEDS: Exploratory Learning

Moving back away from the developer oriented courseware element catalog of NEEDS, a third content-based index is provided for access to information through unstructured queries. Synthesis hypermedia courseware is designed along a navigational path (concept map) laid out to suit the original course and curriculum application. The pedagogical goals of Synthesis include active learning - exploring courseware in ways in which it may not have originally been organized. For this purpose, NEEDS implements a Wide Area Information Service (WAIS) [Kahle et al. 1992] index of any textual content of WWW based courseware. With access to this index provided through a WWW interface as well, additional functionality can be added to each piece of courseware: support for user queries on each HTML page. In this way, courseware users have access to the full courseware-curriculum matrix from any point (implemented in HTML at least) within it.

As a general purpose vector representation-based information retrieval engine WAIS provides a robust protocol for delivering network resources. However, the strength of its information service protocol is often masked by quirky query responses. To combat this problem, we are working to apply the knowledge base created for formal indexing in NEEDS to unstructured queries. One method is to assign a NEEDS *context* which identifies resources using the indices of the structured courseware module and element databases. This context can also be used to augment unstructured queries posed by the user, steering response of the WAIS server toward NEEDS-relevant aspects of the query. For instance, the word 'current' relates to several contexts and might cause WAIS to retrieve documents from electronics, fluid mechanics, or history. The query might indicate which of these contexts is relevant and replace or augment the ambiguous term, improving search performance.

7. NEEDS: Supporting Discussion

Perhaps the most obvious omission from the NEEDS implementation description thus far is support for communication and teamwork, two of the most important remediation targets shown in Figure 1. An opportunity for such communication is the 'think' questions

sprinkled throughout the multimedia case studies pose. Outside of a networked environment, responses to these open-ended problems go no further than the workstation on which the courseware is run. The transition to HTML-based courseware made available on the WWW brings about an additional opportunity for these “think” questions: active discussion. Hoadley et al. [1995] describe a computer tool for carrying out discussion in the format of a kiosk. This idea has been extended to a networked framework and implemented within the NEEDS architecture. The main features of the discussion tool are:

Topical Discussion: Any Synthesis-registered user can create a kiosk for the purpose of carrying on discussions. An array of topics can be entered (as multimedia documents) to spur discussion.

Labeled argument transitions: To respond to a comment or topic, users select a transition of thought (e.g. and, or, but, questions, definitions, etc.) from those selected by the kiosk owner as valid. An additional area is provided for the expression of opinion rather than argumentation.

Argument map: An overview of the argumentation topology is presented through a hierarchy of topics and transitions displayed as a hypermedia starting point for exploration.

Hypermedia content: HTML is supported throughout the discussion server; any resource on the WWW can thus be pointed to help support a position, define a term, or even provide for correspondence through e-mail.

Electronic mail integration: When entering a comment, a user can opt to receive e-mail whenever someone else elaborates upon it. The discussion system thus becomes more active, drawing participants back into the discussion to exchange ideas.

Content indexing: Implementing the system in the framework of NEEDS makes available the content indexing methods described above. Users can go directly to interesting parts of discussions without having to traverse the argument map.

Discussion groups can be used in a number of situations, from the above mentioned “think” questions to courseware evaluation, expert mediated discussion, etc. In their basic format, they are related to the USENET news servers again providing a familiar idiom for

discourse. However, better organization (news articles have a single transition - RE: - which lacks the expressive power to accurately organize discussion) and complete support for hypermedia comments through standard WWW browsers improve on . This portion of NEEDS is in its infancy but is seen as an important step toward making both the infrastructure and the courseware it delivers more active.

8. An Illustrative Example

As an example of the type of material typically available within NEEDS, we will concentrate on the multimedia design engineering case study project, a collaboration among UC Berkeley, Tuskegee, and Stanford. Subject areas for the case studies have ranged from computer, automobile, toy, and industrial tool product cases to the highly successful UC Berkeley collegiate record holding human powered vehicle. Each case brings the student a different view of design issue exploration, multidisciplinary engineering problem solving, and concurrent engineering solutions based on the needs of the product, organization, and industry. Analysis, history, simulation, and experimentation are included where appropriate. Links to engineering texts are included to provide theoretic background underlying the design decisions presented in the case study. Other links tie the design activity to specific artifacts to help ground the reader in the basic context of the design project. All of this information is organized around a product life-cycle navigational backbone, or concept map. Extensive user testing has shown the multimedia case study to be effective in communicating not only the technical information presented in the case but also the rich contextual information that is vital toward supporting open-ended design problem solving [Hsi and Agogino, 1994]. These studies are in line with similar results of design studies of 'learning to do' which compare hypertext to non-hypertext reference sources [Lehto and Zhu, 1992]. Case studies of design, particularly classic design failures, have been posed as a key means of communicating design methods to young engineers [Petroski, 1994]. Hypermedia case studies have also proven successful for teaching design in architecture [Domeshek and Kolodner, 1993].

Originally implemented as HyperCard stacks on a Macintosh or as ToolBook volumes on the PC platform, the case studies have been ported to the WWW to make them more readily available as networked resources. Local indexing and navigation is based on a central concept map of the design life cycle which is augmented by case-specific indices, glossaries, and 'connections' (links outside of the current context to promote exploratory learning). This navigational scheme has proven effective for a variety of user groups [Hsi and

Agogino, 1994]: novice users navigate along a prescribed path, rarely deviating; more experienced user exploit free form navigation, jumping from concept to glossary to other concepts or using the ‘connection’ button to explore ‘lateral’ links to other cases, historical information, or textbooks. A set of case studies is shown at left in Figure 6 along with a typical navigational path.

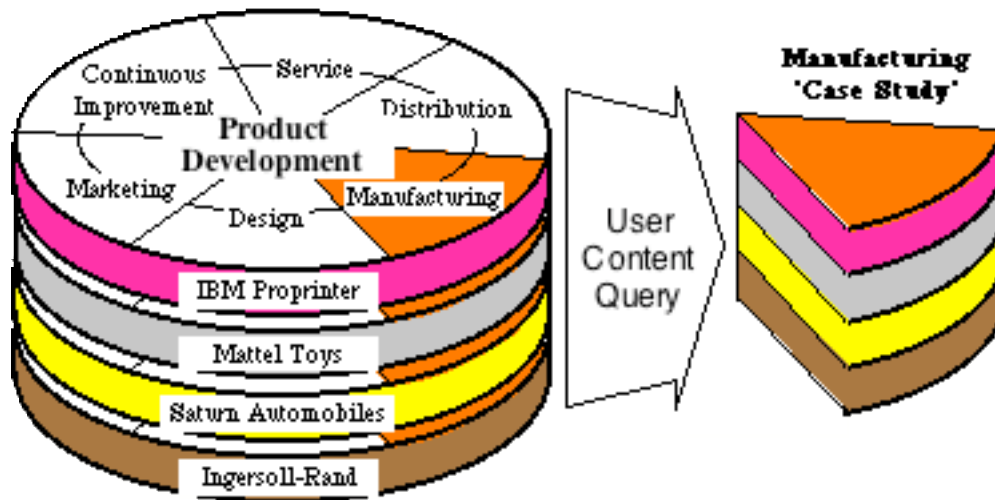


Figure 6. The set of design case studies shown on the left is transformed into a new manufacturing 'case study' by user query to NEEDS about manufacturing.

As a group the multimedia case studies could provide the basis for an engineering course, but are equally effective for augmenting existing curriculum elements. They are ‘Synthesis rich’, highlighting multidisciplinary solutions to open ended design problems while highlighting teamwork and providing engineering roles models through interviews of project participants. The concept map used as the navigational backbone throughout the set is designed to emphasize the product life cycle and its impact on the design team and process. To realize the generality of purpose we conceptualized as the courseware-curriculum matrix, NEEDS must provide for transitions like the one shown in Figure 6. The original case studies organized around the life cycle of a single product are transformed by an unstructured user query over the courseware content database into an ad hoc case study of manufacturing techniques across several products and organizations.

9. Lessons Learned

Courseware must be modular. Faculty are reluctant to take entire courseware modules and adopt them into a local curriculum without modification. To be useful in the broad context of engineering education, courseware must adapt to the needs of varied curricula because the curricula rarely adapt to the courseware. Conceptual modularity is also a key issue - for example, modules designed as a laboratory guide can also offer a virtual lab experience for those who do not have access to the actual hardware.

There is no single access mode. We have discovered three basic modes of access for NEEDS and attempted to provide tools that are effective for each. Faculty looking for courseware to use as a piece (see above caveat) are familiar with the library search paradigm and can adopt it easily. Developers looking to use the courseware collection as a 'clip art' collection appreciate fast, visual access by file type and keyword. Exploratory learning is supported through a content index which identifies navigational starting points in network resources.

Network access is critical. To learning resources described must be made available using standard network interfaces like http, ftp, gopher. Closed software systems prevent resource sharing and pose portability problems. The value of the WWW in making learning resources easily available far outweighs any shortfalls imposed by its primitive user interface. The web is the clear distribution medium of the future, NEEDS has embraced it and will continue to do so both for distribution and as a required courseware deployment platform.

Standards provide robustness and scalability. NEEDS did not develop along international standards by accident. The MARC standard lets us apply a wealth of cataloging experience gained in the library community. International networking protocol standards like http, ftp, and WAIS open the system to innumerable resources both current and future. Emerging standards like Z39.50 are being studied for future extensions of NEEDS.

10. Open Issues

Our experience also suggest some opportunities for further growth beyond incremental refinements to the current NEEDS system. Perhaps foremost among them is the integration of discussion into courseware. We have only limited experience in applying our discussion

tool within courseware modules. Fostering time and distance independent discussion among students and teachers within the context of courseware offers exciting educational possibilities. Collaboration with the Knowledge Integration Environment (KIE) [Bell et al., 1995] project promises exciting opportunities for doing just this.

Courseware quality is an extremely important issue and one for which we have taken some preliminary steps. At issue are: the appropriate level of completeness that distinguishes courseware modules from potential courseware elements, new roles that develop as publishing responsibilities are shared between NEEDS resource managers and the author, the utility of automatic resource discovery and cataloging and the caveats attached to the pointers to such information, the extent of a courseware module containing virtual or dynamic hypertext links (provided by content indexing and discussion servers), and of course assurance of initial and continued technical accuracy of such open-ended modules.

We have required courseware developers to include instructor's manuals for courseware modules. In a student centered, exploratory learning system such information is unlikely to be found. The question is: Can distance-independent learning maintain the quality that these additional materials strive to guarantee?

A final issue is how these network resources integrate with current textbook-based curricula. We are embarking on an experiment with John Wiley publishers to make texts available as network resources right along side of our courseware modules. This promises to reveal interesting patterns of use that will direct the development of a networked model for educational publishing.

11. Acknowledgments

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