

ACT1: Adaptive Courseware Technology

1. PROJECT GOALS:

This project focuses on a technology infrastructure that supports the design of adaptive, web-based learning experiences, the integration of learning materials with those designs, the instrumented enactment of the designs with learners, and reflection by educators on the designs using the collected instrumentation. The principal constituents of this infrastructure are an authoring technology, the Courseware Authoring and Packaging Environment (CAPE) (Howard, 2002), and a web-based delivery platform, the experimental Learning Management System (eLMS) (Howard, 2003).

Adaptive (and adaptable) learning designs of the kind supported by CAPE and eLMS address several issues of concern to VaNTH, as well as other educational “communities of practice” (Wegner, 1998). First is support for learner-centered design (Soloway, Guzdial, & Hay, 1994). Constructivist learning theories emphasize the importance of the individual learner’s background, interests, and motivation to his or her success (and satisfaction) with particular learning experiences. The HPL framework (Bransford, Brown, & Cocking, 1999) therefore establishes “learner-centricity” as one of a set of “lenses” through which a designer should reflect on the learning situation. Web-based learning (as a medium) offers potential benefits for more learner-centered designs. Such experiences can be extensively instrumented, and observations can be collected in an unobtrusive way, to support design reflection, specifically what Donald Schön would call *reflection-on-action* (Schön, 1983). They can be made more responsive to individual learners through adaptations based on prior knowledge, individual responses to questions, or elective actions. Adaptive designs can also permit learners to more actively tailor learning experiences for themselves, with designs responding with appropriate forms of scaffolding.

Learner-centered design of online learning experiences focuses on *enactment-time* uses of adaptation. There are other contexts where adaptability is also relevant to a community of practice such as VaNTH. We assume that one aspect of their communality is that educators act cooperatively to create, share, and evolve learning designs. The first of these additional contexts involves adaptability at *assignment-time*. Learning designs are more likely to be shareable among educators if they can readily tailor them to their particular learning situations. This kind of adaptability is strongly related to learner-centered design, and indeed can be seen as a pathway that can ultimately lead to designs that support adaptation directly by learners. The second, *design-time* adaptability, concerns facilitating the construction of new or derivative designs within a community by sharing design abstractions (pedagogical strategies) and related design elements, materials, and resources. The adaptability of these assets enables what Gerhard Fischer has called *constrained design processes* (Fischer & Lemke, 1987) that facilitate the efficient application of more general insights from the learning sciences in a domain-specific context, and that foster consistencies as the basis for community-wide reflection on designs promoting collaborative improvements over time.

When classroom-based instruction is the central feature of the learning environment, web-based learning experiences can play roles that complement classroom learning or even reshape the relationship between learning inside and outside the classroom. Outside-class elements of these *blended learning* designs (Ganzel, 2001) can contribute to the adaptability of the learning experience as a whole. What can be learned about learners prior to class through formative assessments embedded in web-based elements can inform an instructor’s judgments about adapting the classroom learning experience, particularly since technology can provide this information in a timely way. For example, such knowledge can permit selecting from a set of pre-planned alternative classroom activities.¹ Classroom feedback devices (such as the personal response systems employed by VaNTH) can not only facilitate dynamic adaptation in the classroom, but also the selection of follow-up activities scaffolded by web-based learning. These follow-up activities can provide more immediate diagnostic feedback than traditional graded homework assignments, helping learners to contemporaneously reflect on their learning in the classroom. They can also contribute to reflection by educators on the overarching learning design.

¹ Consider this an extension of Schön’s *reflection-in-action*.

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Our interests in these various aspects of and roles for adaptability provide then the context and impetus for the work of our project. Fundamental to our work is a view of educators as *designers* of learning experiences: that they create, extend, evolve, and share learning designs. As a central feature of their ability to act as designers, educators collect and analyze information essential to their reflection on design situations and reflect in some multi-dimensional way; for example, employing the “lenses” of HPL. Finally, as reflective practitioners, educators use experiential learning to evolve their learning designs, in an improvement enterprise sustained over time whose context is increasingly communal.

2. ROLE IN STRATEGIC PLAN:

With its infrastructural focus, this project supports multiple goals from the VaNTH Strategic Plan. Fundamentally, it supports the goal of creating a body of curricular materials in bioengineering, and it provides technology that can be used by others outside of VaNTH to repurpose these materials in creating their own learning experiences. It further supports the goal of applied research in learning science by facilitating experimentation and data collection through a flexible authoring technology and instrumented delivery platform, capabilities that also support reflection by educators on their learning designs. Finally, we support the goal of providing learning technologies that promote effective education in bioengineering by working closely with the other thrusts of the ERC and bioengineering educators in collaboratively planning and pursuing interventions in which learner-centered design can play a significant role.

3. METHODOLOGY:

The CAPE authoring environment is based on a paradigm known as model-integrated computing (Sztipanovits & Karsai, 1997). In this paradigm, multi-aspect, domain-specific visual modeling languages are employed to construct design models as the basis for synthesis by transformation to the input representations of analytical engines or execution environments. The CAPE modeling language is specialized to the domain of designing web-based adaptive learning experiences, and an execution environment for CAPE designs is provided by the eLMS delivery platform.

The CAPE environment was created as a refinement of the Generic Modeling Environment (GME) (Ledeczi, et al., 2001). This was done by creating a formal specification of the CAPE modeling language, as a meta-model, together with constraints establishing the language’s abstract semantics. The resulting domain-specific specialization of the GME is extended with components that assist CAPE designers in specifying learning designs in various ways, such as model-checking and design-time previewing, and that transform the design specifications into the enactable representation of the eLMS platform. CAPE uses model abstraction facilities of the GME to support abstract learning designs enabling the reuse of adaptable pedagogical strategies.

CAPE models capture many kinds of design specifications for web-based learning experiences. Sequencing models specify behavior associated with a learning design embodied through a set of hierarchical, interconnected, scoped, and typed containment elements. Such specifications involve content elements (static or dynamic), formative or summative assessment elements, and adaptation elements. Adaptations are specified using conditional delivery concepts in conjunction with a data modeling facility. To increase expressiveness, these visual modeling capabilities are extended with derived data, logical expressions, statements, and functions specified in the Python dynamic programming language. CAPE sequencing models support both procedural and non-procedural execution semantics.

Complementing these behavioral specifications are models that establish learning objectives and their associations with content knowledge represented by domain taxonomies. Such specifications contribute to understanding the designer’s intent and therefore contribute to reusability. They also permit analysis for curricular coverage of a corpus of learning designs. Resource models represent dependencies of a design on static, file-based digital content, together with specifications of metadata for these resources that can be standards-based or specialized to the community. Resource models also specify the logical arrangement of resources, which are packaged by CAPE for deployment on the eLMS platform to satisfy references at enactment time.

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The eLMS is a web services platform realized using the Zope web application server (Latteier & Pelletier, 2002). Web services are provided to manipulate several kinds of domain-specific objects such as classes, users, courseware, assignments, and enactments. One use of these web services is to support content interoperability, where active content elements in a learning design (Java applets or servlets, for example) can interact with the design specification at enactment time to coordinate their operation, to retrieve information, or to contribute to the record of a particular learner's use of a courseware. Another example is platform interoperability, where other learning platforms can coordinate rosters and assignments, and initiate or continue the enactment of an eLMS courseware with a learner.

The eLMS provides a sophisticated content management system implemented through extensions to the Zope server and its underlying object-oriented database called the ZODB. File-based resources required by a learning design (web pages and multimedia) are version managed such that multiple versions of a resource can be in use simultaneously. The version management scheme is based on "digital fingerprinting" of the resources and knowledge of the association of content versions with versions of a learning design. Such associations are created by CAPE at the time it generates the enactment-time representation of a learning design for uploading and persistence on an eLMS server.

To support design reflection, eLMS provides a data mining facility that educators can use to query information from automatically collected instrumentation. Every interaction between a learner and a learning design is recorded by eLMS during enactment, and additional instrumentation can be specified by a learning design, typically as a refinement of the more detailed record. The data mining facility supports complex querying based on compound pattern-matching specifications. The results of these queries are returned in XML that can subsequently be loaded into general-purpose analytical tools. The data mining facility is itself supported by web services, so that extraction of information from eLMS delivery records can be integrated directly into an analysis tool or employed by another learning platform.

4. ACHIEVEMENTS:

During the past year, the fifth of our project, we have focused on some important new integration capabilities and the initial introduction of a repository facility that supports CAPE designers. We have continued efforts to improve the usability and adoptability of the infrastructure, along with efforts addressing dissemination and sustainment.

We have undertaken work in three areas of technology integration: platform interoperability, non-learning content interoperability, and just-in-time learning. The first of these concerns interoperation of eLMS with commonly available course management systems (CMS). As an initial effort in this area we have constructed a "building block" integration of eLMS with the Blackboard Learning System. This commercial CMS is in use at three of the primary VaNTH institutions, and it has a large market share among academic learning platforms. It was the first CMS to offer any integration/extension capabilities. The eLMS Building Block permits instructors using Blackboard to form an association between a Blackboard course and an existing eLMS class, or to create a new eLMS class for this association. Rosters and assignments can be synchronized between these objects from Blackboard. Instructors can make assignments of eLMS courseware to their Blackboard course, and learners can access these assignments from Blackboard just as any other assignment. Further extensions of this building block will permit instructors to update Blackboard gradebooks by pulling information from eLMS delivery records. At the time of this writing, Vanderbilt and Northwestern have committed to evaluating the eLMS Building Block for institutional deployment. Deployments at other VaNTH institutions will be pursued in parallel.

To decrease effort in creating learning experiences, and to exploit capabilities of technologies that VaNTH educators may already use in pedagogical roles, we have been interested in content interoperability with non-learning technologies within web-based learning designs. Our efforts in this area have focused on MATLAB, from MathWorks, as a vehicle for understanding opportunities and challenges. MATLAB is a general-purpose computational engine, with domain-specific extensions, that also provides visualization and user interaction capabilities. Our goal in supporting content interoperability with MATLAB was to leverage existing experience and to facilitate pedagogical uses of its extensive capabilities in web-based

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learning. The established integration framework permits licensed student users of MATLAB to view and interact with MATLAB elements of CAPE-authored learning designs. Since MATLAB is a desktop application, the web integration was effected using Microsoft's ActiveX technology and is therefore limited to Microsoft Windows users and the Internet Explorer browser. CAPE-authored learning designs can use MATLAB for visualization or computation by supplying (or dynamically generating) M-code—the scripting language of MATLAB. MATLAB user interfaces can also be constructed using GUIDE, MATLAB's graphical user interface development environment. These interfaces can communicate information back to eLMS using web services for inclusion into a learner's delivery record, or they can retrieve delivery-specific information from eLMS for use in their services. These integration capabilities are being employed initially within VaNTH for a bio-instrumentation web-based learning design where MATLAB is used to provide a suite of analytical workbenches.

Another aspect of platform integration is being pursued in the area of just-in-time learning. These efforts concern embedding eLMS learning experiences directly within another tool. The vehicle that we have chosen to pursue these objectives is CAPE itself, or more precisely the GME upon which CAPE is realized. We are motivated by the recognition that integrated documentation resources often lack depth in terms of context, since the capabilities they describe can often have many potential task contexts. Context is often the distinguishing feature between “telling” and “teaching”. Our aim is to complement integrated documentation with sets of tutorial resources for just-in-time learning that place tool capabilities into more extensive task contexts. To support this aim, we have created a generic extension component for the GME that permits eLMS courseware to be accessed directly from within any GME-based modeling environment. Users are presented with a menu of available tutorial resources based on the current modeling language loaded into the GME, or for the GME itself. Future work in this area will focus on recommendation capabilities that will assist users in selecting tutorial resources.

The VaNTH Repository is a multi-faceted resource supporting dissemination for the ERC. One facet of the Repository is support for sharing learning designs, design patterns and elements, and content elements and resources among CAPE authors. In this context, interoperation with the CAPE authoring environment is a preeminent concern. We have pursued an approach to this interoperation that promotes usability and hides as much of the underlying complexity of maintaining repository integrity as possible. The repository interface is multi-view, searchable asset browser with drag-an-drop capabilities to and from CAPE projects. Complexity enters in maintaining consistency among interrelated sets of elements that typify CAPE learning designs. Within CAPE projects these interrelationships involve much more than containment; for example, they include project-scoped referencing and derivation. The repository interface identifies element “closures”, and it manages transfers to and from the Repository to satisfy dependencies. Recognizing that assets inevitably evolve over time, it also supports versioning.

Ongoing work of the project focuses on improving the usability and adoptability of CAPE and eLMS. The Repository (described above) provides one avenue for this work. Throughout the evolution of the infrastructure, our project has been asked to provide exemplars of techniques for applying CAPE in a number of learning situations and of approaches to solving particular problems. These annotated exemplars provide an effective way to show users how CAPE can be used. Seeding the Repository with these accumulated assets can encourage the use of the repository and of CAPE itself. Augmenting online documentation with task-focused learning resources using the new just-in-time learning capabilities is another avenue for improving the adoptability of CAPE. In addition to scaffolding the use of eLMS from other learning platforms, we have extended its online documentation and have redesigned the courseware delivery interface to support the increasingly popular Mozilla family of browsers.

To support VaNTH dissemination objectives, we have established an additional eLMS server (try.elms.vanth.org) that will support trial use of eLMS-based learning experiences outside of VaNTH. This platform will support initial evaluation by educators and well as evaluative use by classes of learners. We have also established a content facet of the VaNTH Repository to contain assets associated with classroom-based VaNTH modules. CAPE continues to support web-based installation, and we are actively addressing issues of enabling trial use of the technology. We are exploring these and other adoption-related issues with VaNTH-affiliated institutions and others outside VaNTH. These experiences will feed back into our efforts at packaging the technology to increase adoptability.

5. OTHER RELEVANT WORK:

Computer-based adaptive learning has been the subject of inquiry for over 35 years. Two active (and strongly related) technology communities—intelligent tutoring systems (ITS) (Murray, 1999) and adaptive hypermedia (Brusilovsky, 1998)—are modern expressions of this interest. Fundamentally, these technologies employ a suite of learning experiences (which may or may not be individually adaptive) that provide coverage for some knowledge domain. The essential adaptive element provides guidance to the learner on engaging particular learning experiences based on recognized misalignments between explicit models of expertise and the learner's current knowledge, together with some understanding about how available learning experiences can address these misalignments. Our technology infrastructure relates to these systems in providing support for constructing individual learning experiences, in particular those that can be highly adaptive and that can preserve and communicate state between experiences. Adaptability at this level can (and typically does) involve representations of expertise, the current state of the learner, and how the design can adapt in response to recognized differences. While not a design objective for our infrastructure, it is possible that CAPE could be used to design the adaptive “super-structure” of ITS, in that it provides general-purpose representation and computation capabilities and supports non-procedural execution. Advanced features of modern ITS, such as mixed-initiative, natural language dialoging, might be addressed through integration rather than extension.

Academic work in other areas such as learning services architectures, repurposable content, and delivery infrastructures are also relevant to our efforts. The Learning Systems Architecture Lab at Carnegie Mellon University is developing reference architectures for organizing the services constituting delivery systems for asynchronous distributed learning. We are monitoring this effort for possible future adoption by VaNTH platforms. The LearningOnline Network with CAPA (Kortemeyer, et al., 2001) is an NSF ITR project at Michigan State University whose goals are related in many ways to those of VaNTH, particularly in the area of repurposable content. LON-CAPA provides a Resource Assembly Tool for repurposing that has similarities to CAPE and can address content at a more “atomic” level. However, CAPE is more robust in its support for adaptive delivery, and in such areas as specifying learning objectives and relating them to domain knowledge. The Open Knowledge Initiative (OKI) is a collaboration involving several universities headed by MIT that is focusing on reusable infrastructures for asynchronous delivery systems. (“What is the OKI Initiative”, 2002) While still early in development, results from the OKI could potentially provide reusable infrastructure components that could reduce effort in the development of the eLMS platform, or even provide an alternative delivery infrastructure to eLMS, if sufficiently extensible.

6. FUTURE PLANS:

We see VaNTH as initiating a transformation of an educational community of practice, one motivated by the application of constructivist learning theories to designing and evolving learning experiences for the community. The collaborations between VaNTH educators and the other ERC thrusts have resulted in learning designs that are predominantly for classroom-based learning experiences, with limited roles played by learning technologies. We do not see this as surprising, or disappointing, considering the challenges of pursuing such a transformation against the backdrop of the prevailing education system. Rather, we recognize that many VaNTH module development efforts were initial exposures to constructivist learning theories for educators and regard the resulting designs as evidence of innovation *within* the current system. Addressing learner-centered design through adaptive learning experiences performed outside class is a rather radical departure from current practice where learners are expected to adapt to the instruction, not *vice versa*. There is a significant increase in effort to design learning experiences that recognize and respond to the needs of many actual learners, or even to understand the nature and extent of individual learner differences and their relevance to the learning situation. The “chasm” to be crossed in adopting a technology infrastructure that specifically targets learner-centered design is more conceptual and cultural than technological. The promise of more equitable and accommodative learning experiences may simply not be sufficient motivation for educators to expend the effort required to pursue learner-centered designs using adaptive web-based learning, regardless of the features or attributes of a supporting infrastructure.

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In many ways the designs of CAPE and eLMS anticipated that these barriers could be overcome by the transformative implications of constructivist ideas about teaching and learning. We assumed that educators would be motivated by these ideas to engage in the inquiry and reflection necessary to consider and pursue more learner-centered designs. We fully acknowledge a kind of “blindness” created by this expectation. We did not view the technologies as vehicles for motivating or teaching learner-centered design, but rather as platforms for supporting its practice. However, we did anticipate that sharing learning designs is a vehicle for communicating ideas about design, and the visual design representation employed by CAPE, its support for representing abstract designs and design annotation, and its repository-based support for design sharing are reflections of our concern for promoting this kind of communication. As we move forward, we recognize that CAPE and eLMS must be “packaged” and promoted in ways that motivate and teach educators about learner-centered design. As mentioned earlier, seeding the Repository with design exemplars and patterns, and then scaffolding these assets with learning resources provided through the new just-in-time learning capability, can be effective packaging responses to these challenges.

The further diffusion of CAPE and eLMS within the VaNTH community and other educational communities of practice will also be influenced by the “liveliness” of the infrastructure. Technologies are adopted not only because of their past, but also because they have a future. We are therefore pursuing additional contexts for continuing the work that we have begun in VaNTH, so that as educators become more interested in learner-centered design there will be capable and mature technologies to support them. There are a number of proposals currently under development or pending award in which CAPE and eLMS play roles, including an NSF STC and another ERC. There are also a set of smaller proposals for particular improvements to the technology infrastructure that have been put forward by VaNTH educators.

Other improvements are yet planned with funding available from VaNTH. One aspect of these improvements concerns maturing the repository facility supporting community-based authoring of CAPE learning designs. We see design composition and derivation as concepts best explored within the constrained contexts of communities with related learning situations, related pedagogical strategies, and related infrastructure. The VaNTH Repository is a promising vehicle for pursuing this perspective. The alternative to this kind of situated inquiry appears to be merely asserting *there is reusability* because there are standardized interchange representations for designs and assets, metadata to describe them, and repositories to contain them.²

Blended learning designs are the most likely candidate for adaptive, web-based learning experiences in the university setting. We have been, and continue to be, interested in capabilities for coordinating inside and outside class learning activities used within such designs. Simple coordination mechanisms for synchronizing classroom-based learning activities with web-based activities are being extended with “instructor-in-the-loop” capabilities that allow instructors or teaching assistants to conditionally play roles within online learning experiences performed by learners. These capabilities can be used to support forms of scaffolding where human diagnosis and remediation complement adaptive designs. Since online learning experiences can seldom be conceived initially to support a broad range of adaptive behaviors, these human intervention capabilities are a critical aspect of design refinement. That these interventions can be captured as a part of learner delivery records is also important to later reflection by designers.

Support for scaffolding early and late design processes with CAPE is another important avenue for our future efforts. We recognize that abstract designs (design patterns) create their own specification “spaces”. The specification task for pattern instances can be more context-specific and therefore made simpler for novice CAPE users and potentially more efficient for routine users. CAPE provides a *wizards* framework that represents our initial efforts in this area. But the specifications elicited by these agents are too stepwise in many instances, and the implementations require more programming skills than we can likely expect of CAPE users. We are eager to explore more flexible and user-definable solutions. We have also begun investigating techniques that support late “re-design” within the enactment environment.

² It is noteworthy that the software engineering community tried a very similar tact, with a reuse problem somewhat less impacted by problems of context, and failed given enormous interest and investments.

7. MILESTONES AND DELIVERABLES:

Here we report our milestones and deliverables for the current year. Our earlier milestones and deliverables are reported in our previous project reports, and our future plans are outlined above.

CAPE

The principal milestone for this element of the technology infrastructure was the release of CAPE 2.3. The principal deliverables associated with this release are the following:

- New repository and just-in-time learning interfaces realized as GME extension components.
- A new web-based installer that integrates three required elements: the GME, Python, and CAPE. (CAPE consists of a GME modeling paradigm and a set extension components and tools in Python.)
- A set of improvements to the CAPE modeling language and supporting extensions., including:
 - enhanced model checking
 - extended support for dynamic content
 - improved Python integration
 - updated integrated online documentation
- Seeding of the VaNTH Repository with exemplars, existing VaNTH designs, and other assets.

eLMS

The principal milestone for this element was the release of eLMS 2.3. The principal deliverables for this release include:

- Support for the eLMS Blackboard Building Block.
- New courseware delivery interface supporting the Mozilla family of web browsers.
- Improvements and extensions to the eLMS data mining facility.
- Support for content delivery from the VaNTH Repository.
- Initial support for synchronizing online and classroom-based learning activities.

8. MEMBER COMPANY BENEFITS:

The project has collaborated with nTara, Inc. and Prof. Robert Roselli of Vanderbilt University in creating a component version of the Free Body Diagram Assistant (Roselli & Howard, et al., 2003). Our contributions to this collaboration included adding user interface capabilities to the student editor and instructor authoring tool, as well as the web services integration of the student editor with eLMS and the XML-based integration of the authoring tool with CAPE. We collaborated with Prof. Roselli to create a FBD diagnostician authored in CAPE that provides much richer feedback to students than the original FDB Assistant. This diagnostician can be configured to provide incremental feedback to learners over multiple diagram construction attempts and report a set of discrete observations that can be used to support CAPE adaptations. We also authored a context-specific help resource that can be accessed by learners whenever the student editor is delivered.

The MATLAB integration activities of our project, described earlier, can promote the use of MATLAB in pedagogical roles, and there are benefits to both MathWorks and educators. MathWorks benefits whenever its technologies are used in an educational setting. Revenue derived from the licensing fees paid by students is the lesser part of the overall benefit, as evidenced by the high discounts. Greater exposure to MathWorks products as students likely increases the probability of use later in the workplace, whether academic or commercial. Educators benefit when they can employ MATLAB, a technology that they may know and routinely use, as an element of web-based learning designs. Such elements can be scaffolded with web-based learning content in various ways, the elements can be dynamically generated to reflect current knowledge about individual learners, and they can be made to record observations about the learner's use for inclusion in eLMS delivery records to support follow-up design adaptation and later design reflection. These opportunities all contribute to the integration of MATLAB resources into a learning design.

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9. PROJECT TEAM MEMBERS:

Larry Howard, Project Director
Zsolt Remenyi, Staff Engineer
Gabor Pap, Staff Engineer
Csaba Garay, Graduate Student

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