Generation of Individualized Middle School Science Materials Based upon Pedagogic Intent of Content Elements

Robert P. Dolan°*, Chris Wilder-Smith°, David Rose°, Jeremy Price°, Mindy Johnson°, Boris Goldowsky°, Kate Brigham° & Patti Ganley°

° Center for Applied Special Technologies (CAST)
* Pearson Education

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<u>Primary author's current affiliation</u>:
Robert P. Dolan, Ph.D.
Senior Research Scientist, Assessment & Information
Pearson
413-367-6199 / bob.dolan@pearson.com

1. Study Objective

The goal of the current project is to develop a technical approach and supporting architecture which supports the dynamic generation of universally accessible learning environments to enable students with disabilities to access, participate and progress in the general curriculum. The four key objectives of the project are to:

1. Develop markup schemes and ontologies for educational content that capture structural and relational semantic information.
2. Develop a transformation architecture and prototype system that can process the XML content created with the educational semantic markup schemes.
3. Study the effectiveness of the ontology-based semantic markup and transformation architecture for generating appropriate user interfaces.
4. Disseminate results and products to educational research, technical, and publishing communities.

2. Theoretical Framework

The No Child Left Behind Act (NCLB) of 2002 and the Individuals with Disabilities Education Act (IDEA) of 1997 mandate increased expectations and accountability for students with disabilities to access, participate, and progress in the general curriculum. As a result, classrooms have a much more varied student population, one that includes students with disabilities who present a broad spectrum of strengths and weaknesses. Teachers are rarely able to provide the ongoing support or adaptations within the curriculum that would allow individual students to overcome their access and learning difficulties. One critical barrier to individualizing instruction is the curriculum itself, which can be inaccessible to many students with disabilities. Rather than offering gateways to learning and understanding, the printed texts and resources that make up the general curriculum often serve as barriers to these students. Print-based textbooks deliver the same one-size-fits-all presentation, information, and levels of support and challenge to every student. With printed books, the entire burden of individualizing instruction and support is left to the teacher. Few teachers have been trained or know how to individualize instruction within the curriculum, and almost none have the time to do so on a consistent basis with their students.

Promising Educational Solutions

Progress has been made in developing technology-based educational approaches that address the needs of students with disabilities. Digital curriculum materials and technology-based learning environments can improve access to the general curriculum for students with disabilities by presenting the same content as printed books, but in formats that are flexible and accessible. The role of technology in improving learning is still being researched but there is a growing array of examples of educational technology that support access and some that are focused on directly affecting learning (for example, Anderson-Inman, Horney, Chen, & Lewin, 1994; Higgins, Boone, & Lovitt, 1996; MacArthur & Haynes, 1995; Erdner, Guy, & Bush, 1998). Further, these user interfaces that support students’ challenges can be customized for each learner.

Actualizing the potential of technology-supported learning is a focal point for a new theoretical educational framework, Universal Design for Learning (UDL; Rose & Meyer, 2000; Meyer & Rose, 2002), which guides the usage of technological tools in building flexibility into the curriculum. The central practical premise of UDL is that a curriculum should include alternatives to make it accessible and appropriate for individuals with different backgrounds, learning styles, abilities, and disabilities in widely varied learning contexts. The "universal" in universal design reflects an awareness of the unique nature of each learner and the need to accommodate differences, creating learning experiences that suit the learner and maximize his or her ability to progress.

Existing research in the area of educational technology suggests that there is great promise in technology-supported learning. Such approaches, while promising, have been developed and implemented technologically as one-off solutions with limited ability to customize based on student needs, and little ability to scale efficiently to foster wide scale implementation in schools throughout the country. In order to be realizable, universally accessible learning environments must be dynamically generated to meet the learning needs of individual students. What is needed is research and development into technological solutions that allow for dynamic generation of universally accessible learning environments that meet the needs of students with disabilities and other diverse learners.

Promising Technical Solutions

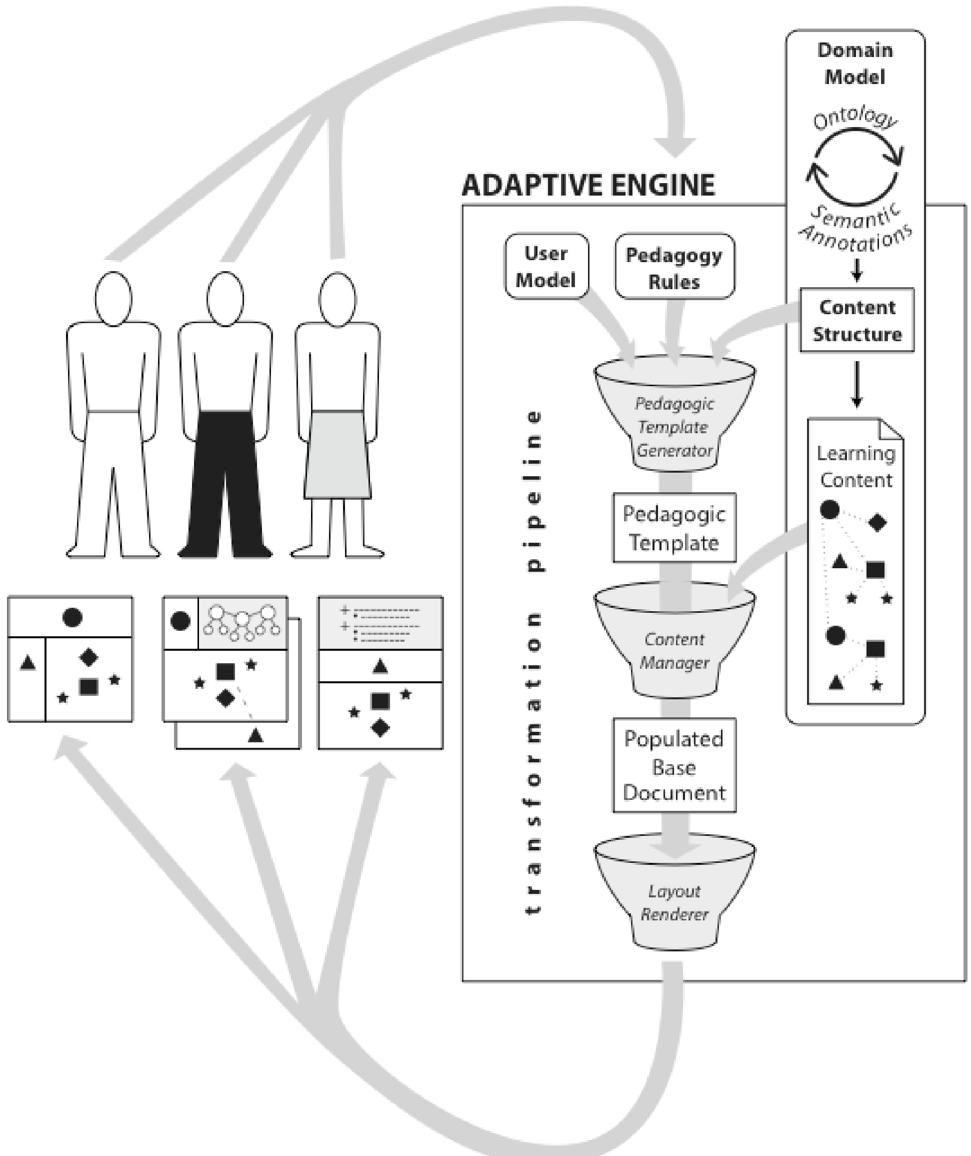
Automating the selection and presentation of digital content requires an understanding of the content structure and the relationships among the various components that make up a particular view of the content. HyperText Markup Language (HTML) provides limited structural semantics to support determination of the significant pieces of this content view and limited relational semantics to support determination of the relationships that exist among these components. This lack of semantic information makes it very difficult to parse an arbitrary HTML-encoded page and lay it out in an alternative view based on the needs of a particular student.

A number of XML dialects provide semantic information, such as ANSI/NISO Z39.86 (ANSI/NISO, 2002), DocBook (OASIS, 2002) and CAST's *e-learning* document type which provide structural semantics, identifying hierarchical structures with nested sections or levels and defining constructs such as sidebars, for example. One specific implementation of note has leveraged a markup approach using an XML Schema called CHORUS (Content Hierarchy with Ontology-based Relationship-Understanding Semantics; Wilder-Smith, 2002), which supports both structural and relational semantics referenced through a formal ontology of structural and relational concepts. Semantic annotation systems (Handschuh, Staab & Maedche, 2001; Kahan, Koivan, Prud'Hommeaus & Swick, 2001) have sometimes separated the semantic markup from the content markup. This approach may lead to greater flexibility and ultimately better results than the embedded hierarchies in CHORUS. The use of ontologies serves to codify the semantic concepts, allowing for machine processing, including inferencing (Kim, 2002). Ultimately, these same ontologies can be used to guide the content authoring and annotation process, which will be of great importance as research findings begin to drive the creation of content management and delivery architectures and large volumes of semantically-enriched content is demanded (Macias and Castells, 2003; Gupta, Ludascher & Moore, 2002).

Systems such as INFO-PRESENTER (Vouros, 1999) have shown that rule-based architectures can be applied to the automatic generation of customized content views based on user preferences and feedback. This approach holds great promise in the educational arena as significant information about student needs, preferences and progress is available. Coupling rule-based systems with ontology-based inferencing should further expand these opportunities for innovation, generalizing the building of rules and resulting in more effective user experiences.

3. Methods

The goal of the current project was to develop a new technology which facilitates the creation of individualized, universally accessible science materials for middle school students, especially those with disabilities. As the foundation for this technology, nicknamed CLIPPS (Custom Learning Interface Production from Pedagogic Semantics), we created an ontology which formalizes concepts of pedagogic intent and semantic relationships across digital educational content elements. This ontology supports a user model-based semantic analysis approach for the selection, sequencing, and presentation of educational content appropriately annotated by content developers. The resulting technology enables the automatic presentation of digital learning materials tailored to individual student learning requirements and appropriate to support classroom learning. In order to evaluate the suitability of this approach, a prototype adaptive engine was built iteratively using formative evaluation techniques (Flagg, 1990; Reeves & Hedberg, 2003). The below diagram illustrates the CLIPPS concept:



The study itself consisted of the following steps, some sequential and some concurrent:

1. Student and Teacher Focus Groups
2. Identification of Middle School Science Content Area
3. Development of Core Content
4. Development and Gathering of Supplemental Content
5. Identification of Supports and Scaffolds, Content Structures, and User Interfaces
6. Development of Student User Model
7. Development of Pedagogic Intent Ontology
8. Annotation of Content
9. Definition of Content Selection, Sequencing, and Presentation Rules
10. Prototype Adaptive Engine Development
11. Final Formative Evaluation

4. Data Sources and Evidence

This development-oriented project relied on formative evaluation methodologies to iteratively evaluate and develop the ontologies, rules, and prototype adaptive engine. This was accomplished through a series of focus groups with middle school science and special education teachers and their students with and without learning disabilities. Seven teacher and student focus groups were held over the course of the project. Specifically, the purpose of these focus groups was to:

1. Identify appropriate middle school science content area.
2. Inform and validate our creation and selection of content and interfaces.
3. Solicit information to support development of user models

Identification of Middle School Science Content Area

In consultation with the middle school science teachers before, during, and after the focus groups, we identified photosynthesis as the middle school science unit on which to develop source material for this study. Teachers provided us with copies of the materials they use in teaching photosynthesis for our analysis so we could best understand how to develop materials that supported their teaching.

Identification of Supports and Scaffolds, Content Structures, and User Interfaces

Through our student and teacher focus groups we identified a set of technology-based supports and scaffolds, content structures, and user interfaces for initial consideration. These interfaces were chosen so as to underscore the needs of students with learning disabilities, by guiding focus group participants through the process of identifying those which they feel would be most useful for students. This effort supplemented the research team's expertise with the development of such techniques across a range of content areas.

Development of Student User Model

The user models provides the relevant context-specific student learning characteristics that serve as input parameters for the content selection, sequencing, and presentation rules. This process was informed iteratively through the student and teacher focus groups. With the UDL framework in mind, we conducted an extensive literature search of extant user models. The final user model is a combination of existing and new UDL-based characteristics.

From the teacher focus groups we learned that characterization of students could be enhanced by developing a set of survey questions based upon UDL principles. The results of this survey were translated into the final user model parameters. The survey was administered as an online tool.

5. Results

The final series of middle school focus groups accomplished two major objectives. First, it provided critical feedback on key components of the project: the student model, the questionnaire used to obtain student data, the content selection, sequencing, and rendering rules, and the use and types of supports and scaffolds. This feedback was instrumental in assuring that our approach was based upon current classroom practices rather than being “engineered in a vacuum.” This was most important in development of the questionnaire, in that it forced us to provide teachers with a set of transparent, real-life student descriptors rather than on opaque set based solely on research-oriented principles.

The second major accomplishment of the formative evaluation is that it supported a better understanding of how “ready” teachers and students are for this approach. Having worked with some of the same teachers over the course of the two year project, we noted how teachers progressed from initial confusion over the intent of the CLIPPS approach to an appreciation of the value of customized materials to support individual student learning needs. The entire notion of customized materials is alien to current education practices. In order for the entire set of stakeholders – students, teachers, parents, local education administrators, state education administrators, publishers, and funders of education research and development – to support and incorporate such a new approach toward content delivery, it is critical that they be brought into the design and development process at an early stage. Our work with teachers and on what it takes to have them be both advocates for and users of this approach made this clear.

6. Educational Importance of the Study

For students with disabilities, the print-based textbooks and educational materials that currently dominate general curriculum present an accessibility barrier. This project shows the potential of technology-based learning materials that automatically present core curricular content based on particular students’ learning characteristics and needs. Using the specific example of a technology-based middle school photosynthesis unit, the project demonstrates the possibility more generally of producing pedagogically sound, customizable educational materials for particular students. The project accomplished this by producing a formal ontology that supports a model-based semantic analysis for the selection, sequencing, and presentation of chunks of educational content and technology to present that content which, when appropriately annotated by content developers, is customized for specific learners.

The broad impact of this effort is to provide a model for the development of curriculum designs that are more effective for students, both with and without disabilities, and to enhance the foundational knowledge and infrastructure components for the technical community, including a pedagogy-based ontology, semantic scheme, and adaptation engine architecture.

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