DEVELOPING EDUCATIONAL MATERIALS IN BIOPROCESSING USING AN ONTOLOGY DATABASE MANAGEMENT SYSTEM

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2007

To my mother

ACKNOWLEDGMENTS

I would like to sincerely thank my advisor, Dr. Howard Beck, who has helped me by replying to many late-night and weekend e-mails and has provided ample time to me for guidance. He taught me ontology, object database, Java, and other topics relevant to my research. I also want to thank him because I got an opportunity to know him in person. I feel lucky and proud to be his student, because Dr. Beck is not only a good researcher but also a good human being. I would also like to thank the director (Dr. William Sheehan), researchers (Dr. Dave Mayzyck, Dr. Art Teixeira, and Dr. Dave Chynowyth)and graduate students (Patrick, Beau, and others) of ES CSTC for their valuable help.

Secondly, I would like to thank my committee members who have given appropriate guidance and their valuable time. Dr. Fedro Zazueta introduced the concepts of learning object, and I am very thankful to him. Dr. Joachim Hammer has guided me to see the role of ontology and database in my research; so, I really appreciate his comments. Dr. Art Teixeira has been a great help, because he guided me in developing additional educational simulations for showing various aspects of process. Dr. Roger Nordstedt has given valuable advice by seeing the usability of my work from an end-user perspective.

I would like to thank my friends (Shantanu Mishra [Golu], Jairaj Payyapalli [Paya] , Soonho Kim, Yunchul , Chris, Bruno, Shiva, and Frank Barone) at UF. Also, I enjoyed my time at Transcendental Meditation Center; so, I would like to thank Dr. Alcine Potts and Patricia. Krishna Lunch has been a great place to meet friends and have food, so

many thanks to them. Also, I would like to thank Dr. Jiannong Xin, Danielle, and Dr. Petraq Papajorgji for tea and valuable advice.

Many thanks go out to my parents, Saroj Badal and R.S Badal; my brother, Rahul Badal; my sister, Rachna Badal; our pet motu and other members for their support and love. Lastly, I would like to thank the source of all happiness and good will.

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LIST OF ACRONYMS

ADL	Advanced Distributed Learning
AICC	Aviation Industry Computer Based Training Committee
ASP	Active Server Pages
AURIS-MM	Austrian Research Information System Multimedia Extended
BMP	Biochemical Methane Potential
CERIF	Common European Research Information Format
CMS	Content Management Systems
DARPA	Defense Advanced Research Projects Agency
ES CSTC	Environmental Systems Commercial Space Technology Center
HTML	HyperText Markup Language
IBM	International Business Machines
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
JSP	Java Server Pages
LCMS	Learning Content Management Systems
LMS	Learning Management Systems
LO	Learning Object
LOs	Learning Objects
MAPR	Magnetic Agitated Photocatalytic Reactor
MATLAB	Matrix Laboratory
M-OBLIGE	Multitutor Ontology-Based Learning Environment
OWL	Web Ontology Language

RDF	Resource Description Framework
RMI	Remote Method Invocation
SCORM	Shareable Content Object Reference Model
SEBAC	Sequential Batch Anaerobic Composting
TRP	Technology Reinvestment Project
UV	ultraviolet
XML	Extensible Markup Language
XML FO	XML Formatting Objects
XSL	Extensible Stylesheet Language
XSLT	XSL Transformations

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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May 2007

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Major Department: Agricultural and Biological Engineering

An ontology database management system was utilized for developing an educational outreach program at UF/ES CSTC (The University of Florida's Environmental Systems Commercial Space Technology Center) with the objective of disseminating research information generated at ES CSTC. The purpose of educational outreach of a research center is to educate the targeted audience about various aspects of research conducted at the center. Information technology can facilitate educational outreach by supporting and enhancing various functionalities for success of the educational outreach program.

A database approach to managing and developing educational and training materials (websites, simulations) is presented that utilizes ontologies and object database treatment systems to better manage educational resources and enhance learning of waste treatment processes. Examples in the area of solid waste treatment and wastewater treatment are presented. An ontology is used to define and organize the concepts in the domain, in this case concepts involving the biology, chemistry, and physics of waste treatment. A database, rather than files, is used to store and distribute concept objects.

Web-based data visualization tools are used by instructors to develop and manage course content. Objects can be projected to a number of different presentation formats, including Web sites and printed materials. Evaluation of a 2-D simulation of a bioprocessing experiment showed that Web-based simulation can offer many of the experiences of hands-on laboratory exercises. The immediate advantage of this approach is that educational programs can be more easily produced at lower cost compared with conventional tools currently available.

CHAPTER 1
INTRODUCTION

The educational outreach of a research center is an important aspect of disseminating information generated by research center projects and helping different audiences understand a research project. The purpose of educational outreach of a research center is to educate the targeted audience about various aspects of the research conducted at the center. Information technology can facilitate educational outreach by supporting and enhancing functionalities for the success of the educational outreach program. The educational outreach program involves five important tasks:

- Identifying educational goals and objectives
- Generating and managing educational content that meets goals and objectives
- Creating educational and training material from the content
- Disseminating educational materials to different targeted audiences in a suitable format
- Performing assessment to test the effectiveness of educational outreach program

Statement of Problem

The Environmental Systems Commercial Space Technology Center (ES CSTC) is a commercial research center of NASA located at the University of Florida. This study reports on the research performed to develop a methodology for creating an educational outreach program at ES CSTC with the objective of disseminating ES CSTC research information. The audience to be reached included industries interested in adopting ES CSTC technologies as well as other researchers working in the area of waste recovery and instructors teaching waste management courses. The methodology was developed by applying new techniques in database management and object oriented technology to

create a repository of educational resources needed to disseminate research results and to provide an alternative approach for developing educational materials (Badal et al., 2004a). Various challenges are involved in the development of educational materials, and these challenges are described in this section. These problems include the following:

- Duplication of efforts
- Lack of knowledge reuse between research and educational materials
- Appropriate format for presenting educational material

Duplication of Efforts

A research center generates a variety of information in various forms such as websites, research papers, reports, simulations, and animations. For example, NASA maintains a website for high school students where the students can find information about a space mission. Conventional tools such as PowerPoint (PowerPoint Website, 2006), Adobe Acrobat (Adobe Website, 2006), Macromedia Flash (Adobe Website, 2006), and HTML development tools (Dream Weaver Website, 2006) are presently used for developing educational resources.

Substantial effort and coordination are typically required for creating educational and training materials. Several methodologies have been developed for creating educational and training materials, and most of them are based on the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model (McGriff, 2000). The ADDIE model involves five steps:

- Analysis: The gap between desired learning outcome and the existing knowledge and skills of an audience is determined.
- Design: The specific learning objectives, content, assessment tools, and exercises are documented.
- Development: The learning materials are created.
- Implementation: The learning materials are distributed to a specific audience.
- Evaluation: The learning materials are evaluated by a specific audience.

Conventionally, a subject matter expert provides content and coordinates with an instructional designer who designs lessons based on the content provided. Content refers to the subject or topics covered in an educational program (Online Dictionary Website, 2006). The content is related to the message or knowledge that the user gets from the educational resource. The information technology professional provides information technology tools and support to the subject matter expert and instructional designer. If instructional designer and information technology personnel are not available, the instructors develop their own educational materials. In any case, most of the steps for developing educational materials, as explained in the ADDIE model, must be performed from the start because the instructors have difficulty in reusing existing course materials (Araujo, 2004). Additionally, these steps are focused on developing a specific set of educational materials rather than representing the course content in a generic form, like a network of concepts, that would allow the reuse of knowledge in developing a variety of educational materials. It is important to reuse the knowledge because it can decrease the development cost and time while increasing the quality and accuracy of educational materials (Fisher, 2002). The lack of knowledge reuse increases the volume of educational materials, creating a problem for managing these materials which in turn increases the cost related to storage and maintenance of knowledge. Reusable knowledge can be used in developing educational materials in different contexts and for different audiences (Araujo, 2004). For example, the MAPR website (MAPR website, 2005) was created for teaching the concept of "photo catalysis application of titanium dioxide for treating wastewater". This website contains many important wastewater treatment concepts which are presented in a specific order so a reader can develop an awareness of

the concepts. The concepts illustrated in the website can also be used in other educational programs, but the reusability of the MAPR website is limited because of the following reasons:

- Unstructured content of the website/educational material
- Lack of separation between presentation and content

Unstructured content of the educational material

The unstructured content is defined as "information whose intended meaning is only loosely implied by its form and therefore requires interpretation in order to approximate and extract its intended meaning" (Ferrucci, 2004), that means, the organization and semantics of information are not defined explicitly. Examples of unstructured content include Microsoft Word documents and PowerPoint presentations. The unstructured information of the website (educational material) creates a challenge in reusing a specific concept in other educational materials. Suppose, for example, that a wastewater treatment company is creating a training material for their waste management process, and that they want to teach the concept of photocatalysis (as explained in the MAPR website), but they do not want to teach the concepts irrelevant to their process. The unstructured information of the MAPR website makes it a challenge for the wastewater company to search for the relevant concepts in the MAPR website and decide if the concepts can be used in the company's educational and training material. Of course, the content can always be manually extracted and reused, but this can be a time consuming and tedious task, especially in large educational programs.

Lack of separation between presentation and content

The tight coupling of content and presentation creates a challenge of updating and managing educational resources (Roure, 2003). Presentation refers to the rendering of

educational resource in a specific format like print (W3C Website, 2006). Separation of content from presentation allows a developer to update the content while maintaining the consistency of presentation. Similarly, the developer can change the presentation of an educational program while maintaining the consistency of the content. This improves maintainability and facilitates the customization of educational material.

Lack of Knowledge Reuse between Research and Educational Materials

The information used for educational or training purposes can also be used for research purposes or vice-versa. For example, a researcher can describe a waste management system in a project report using some concepts. These concepts can also be used by an instructor to explain the waste management system. Research and learning processes are interdependent, and they contribute to knowledge (Lyon, 2002). The integration of research and educational knowledge will increase transparency in research, improve the accessibility of research results, and enhance the development of the educational materials with up-to-date information (Lyon, 2004). However, research knowledge in the traditional form of reports, simulations, or mathematical models is not effectively reused for developing educational and training material and vice-versa.

Appropriate Format for Presenting Educational Material

The presentation of educational material in a particular format is highly crucial. Cognitive information processing and information theory has found that certain formats for presenting information are more familiar to the users than others. The familiarity of a format affects learning because it influences human processing capabilities (Lloyd and Jankowski, 1999). The human visual system has the highest information processing capability (Rohrer, 2000). Cognitive psychologists have described human processing as conscious and pre-conscious. Processing graphic information is pre-conscious, which

frees up more conscious processing ability and allows more learning to happen. However, excessive or confusing graphics can hinder learning.

Cognitive psychologists have found that multimedia can affect the students learning (Mayer and Moreno, 2002). Mayer has described five principles that can be used for teaching scientific concepts to students using multimedia. These principles are:

- Multiple representation principle: It is better to use multiple modes of presentation (like words and pictures) than a single mode (only words or pictures).
- Contiguity principle: The corresponding words, pictures, and other multimedia information should be presented contiguously rather than separately.
- Split-attention principle: Multimedia should be explained by auditory narration instead of a text explanation.
- Individual differences principle: The multiple representation principle, contiguity principle and split attention principle are more important for learners with low level of prior knowledge than learners with high level of prior knowledge.
- Coherence principle: The multimedia explanation should not use extraneous words and pictures.

This study involves the development of educational and training materials for engineering processes used at ES CSTC for treating wastewater and solid waste. Engineering processes are dynamic in nature, and it is beneficial to present these processes in a suitable graphical format for effective understanding.

Specific Objectives

- Identify available technologies for facilitating the documentation of ES CSTC research information, which can allow for processing and storage of ES CSTC research information in an appropriate format so it can be shared, accessed, and maintained easily.
- Develop a methodology for generating a variety of educational materials (websites, animations, and reports) while avoiding duplication of effort.
- Present dynamic (simulations, process) and static (equipment details) information in a suitable format to a variety of audiences (high school students, researchers or management professional in the industry).

- Investigate a better method of representing knowledge of a mathematical model to allow the use of knowledge for various purposes including the development of educational materials.

Approach

This study has investigated an approach of developing an educational outreach program utilizing information technology tools with an objective of reusing and presenting the information explicitly, that is, representing information in a structured format such as an ontology. An ontology, an approach to knowledge use/reuse and knowledge sharing (Beck, 2003a), allows the information to be represented as a network of concepts. For example, the details of a lab exercise can be represented as a network of concepts like equipment (bottles, pipes, valves), chemicals, and samples used in the experiment rather than a Microsoft Word document. The ontology can be used for assisting in communication between people, attaining interoperability among computer systems, and improving the quality of engineering software systems.

A content management system (CMS) is used for developing educational materials. A CMS is a database management system used for storing content which includes not only media such as text, images, animations, sounds, and videos, but also concepts in the form of individual words and phrases, rules, and even mathematical equations (Beck, 2003a). The CMS stores content as ontology. Compared to conventional ways that focus on developing educational material in a specific format (PowerPoint, Flash , Microsoft Word etc.), this approach allows for a better method to organize resources, assist in search and retrieval, and generally promote greater reusability and sharing of content. The CMS also has the ability of automatically generating presentations from a database through a process in which the elements of database objects are mapped to a particular presentation format such as HTML, print, Flash, Java Applet and others. The CMS was

used to generate educational simulations rendered as Java Applets, and Web pages rendered by using Java Server page (JSP) technology.

Educational simulations were used for describing engineering processes. These simulations are run in a virtual environment allowing students to operate or manipulate the equipment as well as the simulation process itself. Instructors can show a lab in the form of an animation for explaining various concepts. The students can also change the process parameter to study the behavior of the system. One of the objectives of this project is to present information in a suitable format. . The interactivity of a simulation increases student's learning efficiency (Mclean and Riddick, 2004). Another advantage of using simulation is that the student can access and operate the process anytime and anywhere. Educational simulations have been used for explaining processes (Navarro and Hoek, 2005), so various simulations were created for explaining waste treatment concepts used in three projects in the area of solid waste and wastewater at ES CSTC (Badal et al., 2006).

The static information (for example, geometrical orientation of equipment) was stored in the database and rendered as a webpage. The information rendered as a webpage has links to other relevant information based on the data modeling or the structure of the ontology. The structure of the ontology of projects at ES CSTC will help users to browse project specific knowledge and access relevant information. Any change in the data model or ontology will automatically update the webpage. The static information in the form of reports can also be generated using Extensible Stylesheet Technology (XSL).

Other Related Projects for Managing Research Information

Several efforts are taking place for enhancing the use of information technology in managing research information. These are described in this section.

E-Science

One of the efforts is taking place in the United Kingdom, where E-Science Institute is trying to support and enhance the scientific process using information technology (Roure, 2003). The aim of the E-Science initiative is to allow sharing of resources among individuals and institutions in a flexible, secure, and coordinated manner. E-Science refers to the activities performed by a scientific community in a distributed environment using the Internet. These activities require access to computing resources for data collection, data analysis, simulation, data visualization, and other relevant information (procedure, standard) used by researchers in conducting experiments.

The E-Science project has three layers: data/computation layer, information layer, and knowledge layer. The computation layer deals with the task of collecting data (experimental and simulation) and allocating resources for collecting data . This layer involves distributed computing systems. The information layer deals with the task of representing, storing, accessing, sharing, and maintaining information. The knowledge layer deals with the process of acquiring, using, retrieving, publishing, and maintaining knowledge. This study shares common goals with the E-Science project with respect to information and knowledge layer. However there is a significant difference in the scale of this study - the presented work - and the E-Science project. This study is conducted at the level of a single research center while the E-Science project is conducted at the level of a country (Britain) with the budget of 250 million pounds and has sponsored 100 projects. The content used in E-Science is manually annotated using Extensible Markup

Language (XML) or Resource Description Framework (RDF) while the content used in this study is self annotated because it is stored as an ontology in an ontology database management system. The large scale of the E-Science project poses a challenge for structuring the content as ontology. On the other hand, the relatively unstructured nature of the E-Science project content results in reduced ability to understand and reuse the content.

Austrian Research Information System Project

The Austrian Research Information System Multimedia Extended (AURIS-MM) project involves the development of a semantic web application for accessing research information in Austria (AURIS-MM Website, 2002). The present Web technology is designed for humans to read the content while semantic web, an extension of the current Web, is envisioned to bring structure to its content so the content can be processed automatically by various programs to perform useful tasks (Lee et al., 2001). Researchers need a variety of information, so there should be a mechanism by which they can get the relevant information for doing a particular task. The proposed solution of the AURIS-MM project is the creation of RDF ontologies. This study and the AURIS-MM project share a common objective of managing research information so it can be shared and readily searchable and available among researchers. However, the difference is that the AURIS-MM project has used the Common European Research Information Format (CERIF-2000) metadata (CERIF-2000 Website, 2002) for describing the research information , while this study has developed an ontology of ES CSTC research information for describing the ES CSTC research projects. The ontology of ES CSTC research information was able to capture the knowledge of research projects so the projects can be shared and searched from the level of vocabulary used by researchers.

The initial development of an ontology was a time consuming activity. However, the ontologies can be reused which can decrease the development time in the future. On the other hand, the time required to enter the metadata information for AURIS-MM project is relatively less but the information can be searched only from the level of metadata terminology used in CERIF-2000 and not from the level of natural vocabularies used by researchers.

Dissertation Layout

The literature review for this study is further explored in chapters 2, 3, and 4. Chapter 2 describes the ontology as a technology for documenting ES CSTC research information (objective 1), followed by the methodology for generating a variety of educational material (objective 2).

Chapter 3 describes the approach for representing dynamic information using educational simulations (objective 3). Chapter 3 illustrates the methodology of developing educational simulations followed by a description of the simulations that were created. Evaluation studies are presented comparing explaining waste management process by simulation and by conventional methods (class room lecture and lab experiments).

Chapter 4 describes an ontology-based approach for representing mathematical models and simulations that explicitly exposes knowledge contained in models at a higher level (objective 4). The knowledge can be further used for constructing conceptual models, simulations of similar systems, and educational and training materials. Chapter 4 also addresses several problems with conventional methodology used to develop simulations.

Chapter 5 summarizes contributions and conclusions, and identifies future directions.

CHAPTER 2
CONTENT MANAGEMENT APPROACH FOR DEVELOPING EDUCATIONAL MATERIAL

Introduction

The technology for authoring and delivering instructional materials continues to evolve. At the current time, conventional tools such as PowerPoint, Adobe Acrobat, Macromedia Flash, and HTML development tools are widely used to develop computer-based educational resources in higher education. However, new approaches are evolving that are based on databases, content management systems, and learning objects (LOs). A significant difference between conventional tools and these new approaches is the latter's focus on better representing the content (Dicheva and Aroyo, 2002) - what we know and what we teach - and separating content from presentation - how we teach and how particular concepts are presented. By better defining and representing content, instructors and course authors will achieve greater freedom and flexibility in creating and delivering effective educational materials. These educational materials should be more easily shared, and duplication of effort in developing learning materials can be reduced. In addition, instructional experiences should be tailored to the needs of individual students, not only providing the appropriate level and sophistication of information, but also presenting it in a way that meets the individual student's preferred learning style.

Domains Studied

Educational materials (educational simulation, websites) were created for the following knowledge domains (two research areas of ES CSTC):

Solid Waste Treatment

The solid waste treatment area had two projects. The first project was a bioprocess laboratory called the Biochemical Methane Potential (BMP) lab. The objective of the BMP lab exercise was to determine biodegradability of biological waste material (Course Website for Bio. Eng. Lab, 2004). It involved three major steps:

- Medium preparation: This step involved mixing, heating, and cooling different chemicals to prepare a medium. The medium and inoculum (sludge with bacteria) were added to the sample of solid waste.
- Incubation: The sample, inoculum, and medium were mixed and were stored in a bottle, which was placed in an incubator.
- Sample testing: The biodegradation of the sample was measured at different times using gas chromatography machine. The biodegradability was measured after one, three, five, fifteen, and thirty days.

An operational laboratory system of the BMP lab exercise had nine bottles, one reactor, two gas cylinders, one incubator, and one gas chromatography machine. The biodegradability determination using the physical lab took thirty days to complete. The task of collecting data was divided among groups of students. Expensive chemicals and equipment were used in the lab. The BMP lab was taught in two courses offered in the Department of Agricultural and Biological Engineering, University of Florida. Dr. John Owens taught the BMP lab in an undergraduate level course called Biological Engineering Laboratory (ABE 3062) and Dr. David Chynoweth taught the BMP lab in a course called Applied Microbial Biotechnology/Advanced Applied Microbial Biotechnology (ABE 4666/ABE 6663). Because of the commercial application, this lab

is also consulted by waste management professionals at the national and international level.

The second project was titled "Anaerobic Composting for Recovery of Energy, Nutrients, and Compost from Solid Waste during Extended Space Missions". It involved the treatment of solid waste by a process called Sequential Batch Anaerobic Composting (SEBAC). The fundamentals of the SEBAC process were the same as that of the BMP process. The only difference was in the scale of operation; which means, the BMP project was a laboratory scale of the SEBAC project. The biodegradability test needed by the SEBAC was done in the BMP project. The SEBAC process used five reactors and circulates liquid slurry, or leachate, between reactors in a specific sequence. The leachate was circulated internally, to a reactor containing activated feed, and between the reactors containing mature (old) feed and new feed. It took twenty-one days to treat a single batch of solid waste (Chynowyth, 2002).

Wastewater Treatment

The wastewater treatment area had one project titled "Effectiveness of a Photocatalytic Reactor System for Water Recovery and Air Revitalization in Long-Duration Human Space Flight". This project involved the treatment of wastewater by the Magnetic Agitated Photocatalytic Reactor (MAPR) process. The wastewater was treated using magnetically agitated particles coated with titanium dioxide catalysts in the presence of ultraviolet radiation. The experiments were conducted at different magnetic strengths and with different particle sizes of the catalyst for the purpose of studying the efficiency of the MAPR process (Mayzyck, 2002). The MAPR project involved three major steps

- Sample preparation: The wastewater sample and nano pure water were added to a mixing bottle and mixed for several minutes.
- Sample treatment: The mixture of wastewater sample and nano pure water was sent to the MAPR reactor. The UV light was turned on followed by the generation of a magnetic field by a frequency generator. The frequency generator was operated at a frequency of 20 hz, 80 hz or 120 hz. The sample was treated in the MAPR reactor for a few minutes in the presence of UV light and magnetic field.
- Sample analysis: The sample was collected and sent to the spectrophotometer for analysis and the collecting of kinetic data.

Rational for Structuring and Reusing Information of ES CSTC

The ES CSTC projects involved laboratory exercises in solid waste and wastewater treatment. Typically, the instructions of a lab exercise are available as a paper or electronic document that contains the relevant lab information. For example, the instructions for the BMP lab exercise were available as a Microsoft Word document containing the information on equipment (reactors, bottles), raw materials, catalyst, and methodology (Course Website for Bio.Eng. Lab , 2004). These lab instructions were not structured, which means, the relationships between different concepts (equipment, steps, and raw materials) were not defined explicitly. Several other lab exercises and other educational materials (like lecture notes and presentations) in solid waste treatment also use many concepts used in the BMP lab exercise, but the information cannot be reused effectively because of the unstructured format of the information. Additionally, there is no formal agreement in the way these concepts are defined, which creates communication problems at the level of human and computer. There is a need to organize, process, and retrieve the knowledge stored in the educational materials (lab exercise) so that the content of the educational material can be easily reused and applied to build better educational experiences.

Ontology

Ontologies are a promising technology for knowledge reuse and knowledge sharing (Zheng et al., 2003). An ontology is a collection of concepts and relationships among these concepts in a specific domain (Noy et al., 2000). For example, an ontology of the BMP lab exercise contains the knowledge of anaerobic digestion and the concepts used in a typical wet lab such as bottles and chemicals. The ontology of the BMP lab exercise gives a well-defined meaning to the concepts used in the BMP lab exercise which will allow these concepts to be used in other applications (reports, presentations, and simulations on BMP). An ontology will allow educators at different institutions to share their educational materials, improve the understanding of domain knowledge, and increase the usage of knowledge within an organization (O'Hara and Shadbolt, 2004).

Ontologies can be used for assisting in communication between people, attaining interoperability among computer systems, and improving the quality of engineering software systems. Ontologies are a core component of the emerging Semantic Web movement that attempts to go beyond conventional HTML file formats and other proprietary file formats to better represent content on the Web (Lee et al., 2001). A number of developments utilizing ontologies have been proposed to support a variety of instructional and authoring activities. These developments are summarized in the section "Efforts in Managing and Reusing Content Using Ontologies".

Literature Review

Computer-Based Instruction

Several relevant recent efforts involving techniques for developing computer-based instruction are presented here. The Defense Advanced Research Projects Agency's

(DARPA) Technology Reinvestment Project (TRP) invited proposals for developing authoring tools which could help in lowering the cost of producing computer-based instructional materials (Spohrer et al., 1998). Many industries (publishing and technology) and academia participated in DARPA's TRP project. Apple and IBM proposed ScriptX, an object-oriented and cross-platform standard, for developing CD-ROM content utilizing an authoring technology called SK8. The SK8 technology was focused on providing authoring tools specific to the tasks, which would enable authors to do their job in cost efficient and effective ways. One of the important lessons learned from this project was that intellectual property protection barriers, social conventions, and business model restrictions can prevent people from using authoring tools.

The advent of the Internet had a significant impact on the process of delivering educational content. The Internet was seen as a better medium for delivering educational material than a CD-ROM (Spohrer et al., 1998). The focus shifted from developing specific authoring tools to collaborating within an authoring community using the advantages of the Internet. The Internet enabled the easy distribution and maintenance of educational materials in an economical and efficient manner. The Internet also enabled learners to access the course materials from remote locations like the home or office.

Presently, educational materials are developed using multiple multimedia development technologies such as Macromedia Flash, Shockwave, or Microsoft PowerPoint. For example, Flash animations are created to explain the various concepts of chemistry (Neo/Sci Website, 2006). Authoring educational materials using computer-based tools has many advantages. Computer-based authoring tools can lower the cost of producing educational materials, engage learners by developing interactive and

immersive learning materials, and help educators in customizing and reusing content. However, the management of educational materials becomes challenging as the content of educational material increases in size and complexity. A concern arises about the reusability of the content from technical and legal perspective. Additionally, it is becoming difficult to locate and retrieve relevant educational materials.

Content Management Systems

Content Management Systems (CMS) are being developed for managing the content of educational materials (Learning Circuits Website, 2001) by providing a capability for authoring, collecting, storing, and delivering educational materials. Learning Management Systems (LMS) are used for managing various administrative aspects, such as course registration, of delivering a course. Learning Content Management Systems (LCMS) combine the functionality of LMS and CMS. "A content management system is a distributed software system which treats information in a granular way, enabling the access, versioning, and dynamic assembly of pieces of information, and named content, such as diagrams, tables, images, or pieces of text" (Canfora, 2002). Boiko (2002) defined CMS by the following key processes:

- Collecting: Creating or acquiring content items and transforming the content into standard formats
- Managing: Storing and maintaining the content and their metadata in a repository
- Publishing: Retrieving and extracting the content for producing information in a specific format

Learning Objects

Presently, many educational materials are created without considering pedagogical aspects. Learning Objects (LOs) are a paradigm that emphasizes presenting the domain knowledge within the context of instructional strategies and assessments (Khan, 2003).

A Learning Object (LO) consists of the following components (Sepúlveda-Bustos, et al., 2006)

- Goals and learning objectives
- Knowledge domain: It consists of the knowledge of course content, which can be presented as text, image, animations, or movies.
- Instructional information: It presents the information relevant for presenting the content in a particular sequence and adjusting the sequence and pace of the delivering content based on learner's ability.
- Searchable metadata: It includes the information about the content, which can be used by learners or instructors for searching for a specific LO. It includes information like name of the author, title of LO, or keywords.
- Assessment: It determines the attainment of learning objectives by the students, which can be achieved by using assessment resources (exams, quizzes).

Other important aspects in generating LOs include the graphic design (the way it is presented) and the medium of delivery.

A basic problem faced by the learning community is how to produce and deliver quality content for online learning experiences. International Business Machines (IBM) developed an approach for producing LOs to provide individualized learning experience for learner's specific needs (Farrell, 2004). The content of LOs was produced from the reference books and presentations in a semi-automatic fashion. The learners were able to search the LOs on the basis of media type, intended use, level of difficulty, or keywords.

Several efforts have been going on in standardizing the way LOs are created, managed, and used. Four organizations are developing standards relevant to LO technology: Aviation Industry Computer Based Training Committee (AICC), Institute of Electrical and Electronics Engineers (IEEE) , Advanced Distributed Learning (ADL), and Instructional Management Systems (IMS), Global Learning Consortium (WBTIC Website, 2005).

Shareable Content Object Reference Model (SCORM)

Shareable Content Object Reference Model (SCORM) is a standard developed by ADL for LO (ADL Technical Team, 2004). The development of SCORM had a significant impact on the e-learning industry and on the development of LO. Most of the vendors are developing standards based on the SCORM. The SCORM standard requires LOs to have the following features:

- Reusability: The LO should be capable of being assembled and restructured in a variety of different courses. For example, a LO on "overview of anaerobic digestion process" developed in an organization such as an agricultural engineering department should be able to be usable in the training modules of other organizations like USDA.
- Interoperability; The users should be able to combine LOs from the various sources for designing their own courses.
- Durability: The advancement in the technology should not make a LO obsolete.
- Accessibility: The content developed using LOs should be accessible at anytime from a variety of locations.

Efforts in Managing and Reusing Content Using Ontologies

Several relevant recent efforts in managing and reusing the content (also LOs) are presented here. Most of these efforts have been proposed rather than implemented. Most of the researchers (Angelova et al., 2004; Sridharan et al., 2004; Tan and Goh, 2005; Nicola et al., 2004) have proposed ontologies for annotating learning resources while the presented approach has described a system for storing the learning content in an ontology.

A number of developments utilizing ontologies have been proposed to support a variety of instructional and authoring activities, including hypertext navigation, collaborative learning and training, courseware authoring, user interaction, and information retrieval (Aroyo and Dicheva, 2002). For example, an approach has been

proposed for integrating authoring tools with the knowledge of instructional theories and principles by developing a series of ontologies with the objective of delivering an appropriate instruction method based on instructional theory (Mizoguchi and Bourdeau, 2000). An ontological approach to courseware authoring has been proposed by separating domain knowledge and application related knowledge (Aroyo and Dicheva, 2002). Ontologies have been developed for describing the multimedia content used in educational material. For example, Stanford has developed an ontology for MPEG-7, a standard for describing multimedia content.

There have been several suggestions for making LOs reusable using ontology. One of the suggestions was to create an ontology of the LO metadata which can help users in searching and using LOs (Gasevic et al., 2005). The DocSouth project used domain specific metadata for describing the content of a LO (Pattuelli, 2006). Tan and Goh (2004) proposed the association of domain ontologies with the learning resource for classification, navigation, and searching of learning resources. Multitutor Ontology-Based Learning Environment (M-OBLIGE) proposed a system where ontologies were used as the metadata of web-based educational materials i.e., educational material will point to various ontologies for semantic markup.

The Larflast project structured the learning content by developing a domain ontology in finance and by using the domain ontology for annotating LOs (Angelova et al., 2004). The annotations of LOs were entered manually and were used for linking the LOs with the concepts of the ontology. The ontology of the Larfast project contains 300 concepts. The two types of LOs were described in the Larfast project:

- Static exercises: Used to determine the knowledge of a domain
- Reading materials: Collected from the Internet and related to relevant concepts

The Larflast project emphasized the usage of explicit domain knowledge in describing LOs. For the purpose of authoring course outlines, Yang et al.(2005) proposed an ontology based course editor. Sridharan et al. (2004) proposed an application for managing and searching relevant documents by developing an ontology in RDF.

Nicola et al. (2004) described the use of ontologies in gathering and organizing teaching materials for the construction of a course. The ontology of course content was developed and referenced to the learning resources. For validating the approach suggested by Nicola et al., a course on "ontological modeling" is under development and an ontology of 168 concepts has been developed. Iowa State University developed the domain ontology from a controlled vocabulary in the medical domain (colonoscopy and endoscopy) and used it for annotating a video database (Bao et al., 2004).

Sepúlveda-Bustos, et al. (2006) proposed a methodology for developing LO by applying the approaches of software engineering, project management, and instructional design. The work of Sepúlveda-Bustos, et al. applied the principles of Blooms taxonomy in establishing the learning objectives. The components required to built a LO was represented by an ontology of the components(objective, assessment, metadata, learning assets, etc.) of LO. The ontology was used for identifying and collecting the identified resources. The LOs were rendered as a webpage using Macromedia Dreamweaver, and they were evaluated in an undergraduate course in fluid mechanics. On the contrary, this study utilized ontology for storing the knowledge of resources. This study structured the content of educational materials (website and educational material) as the domain

ontology and the educational materials were generated automatically as explained in "Presentation Generator" section.

Generating Presentations from Content

The content of educational material can be presented in a variety of formats - like animation, website, reports etc. The development of an educational material in a specific format involves three major steps: collection of information, organization of information, and presentation of information in a specific format (Alberink et al., 2004). There are several techniques for generating presentations. One fairly common approach is to use "server page" technology such as Microsoft's Active Server Pages (ASP) (ASP Website, 2004) or Sun Microsystems's Java Server Pages (JSP) (Sun Website, 2004). Server page technology (JSP and ASP) is restricted to the creation of web pages, but has the advantage of drawing content from a database to populate web pages.

Style sheets offer another technique for creating presentations. A Style sheet describes the rules for presenting documents in different presentation style formats on different media like webpage or print (W3C Website, 2006). Separating content and presentation can be achieved by storing the content in a database and generating the presentation by using style sheets (Clark, 1999). The style of a presentation can be specified independently of the actual content, so that the same content can be presented in different styles. For example, multiple websites with different presentation styles (fonts, colors, layout) can be generated from the same content so the content can be presented to a specific audience in a suitable format (CSS Website, 2005). The rationale for using multiple styles is the preference of a specific style by the intended audience. For example, different colors are prominent in different cultures so the background color of the website can be changed based on culture of the audience. Similarly, older audiences

prefer bigger fonts so the font can be changed based on the age of the intended audience. Among other things, this frees instructors (course authors) from having to be experts in graphic design, and they can focus instead on their subject expertise. Instructors can choose from pre-existing styles that were created by graphic design experts.

One of the most well known methods of utilizing independent styles to generate presentations is Extensible Stylesheet Language (XSL) technology (Clark, 1999). In this approach, the style of presentation is described in a XSL Transformations (XSLT) file. Basically, an XSLT provides instructions for how one XML file can be converted to another by telling how a tag in the source file should be converted to a tag in the destination file. In practice the source XML file contains the content to be presented and the destination XML file can be HTML for website generation, XML Formatting Objects (XML FO) for printing, or other formats. As XSL technology can be somewhat tedious to develop, other techniques have been created to convert database objects to presentations where basic elements of style are described in a flexible format (also as database objects) and are used by a program that generates multiple formats (HTML, Applet) from database objects. The style objects that specify details such as fonts and colors guide the program.

Content Management Approach

The approach used in this study applied a CMS for creating and managing educational materials in the area of waste treatment . These systems have the ability to generate presentations from a database through a process in which the elements of database objects – concepts stored in database – were mapped to a particular presentation format such as HTML, animations and other formats as explained in “Presentation Generator” section). Such a facility can provide a valuable component in an information

technology approach to handling educational resources in agricultural and biological engineering. It can promote the sharing and reusing of educational materials within a department and between different departments locally and regionally. The presented approach will change the focus from developing a specific educational material to representing the knowledge of educational material and using generic software applications for generating educational materials.

Components of a Content Management System

This section describes the components of the content management approach used in this study for developing educational materials. Web-based tools were used for entering the details of the lab processes as an ontology in the database (Badal et al., 2004b). Presentations that can take the form of educational simulations, web pages and other formats were then generated from the database using software tools.

Figure 2-1 shows the components of the content management system used for developing educational materials. Central to the approach is an ontology for building formal descriptions of concepts and showing how these concepts are interrelated. The ontology was stored in an object database that provided a physical storage mechanism for large numbers of concepts or objects; the bioprocess lab example contains several hundred. Graph-based and web-based authoring tools (described in section "Tools for Creating an Ontology") were used by instructors to create and manage course content. These tools were integrated with an object database for storing the ontology - structured information. Several different techniques (JSP, Java Applet) were used to automatically generate presentations from this content. Details of the major components of the system are described here.

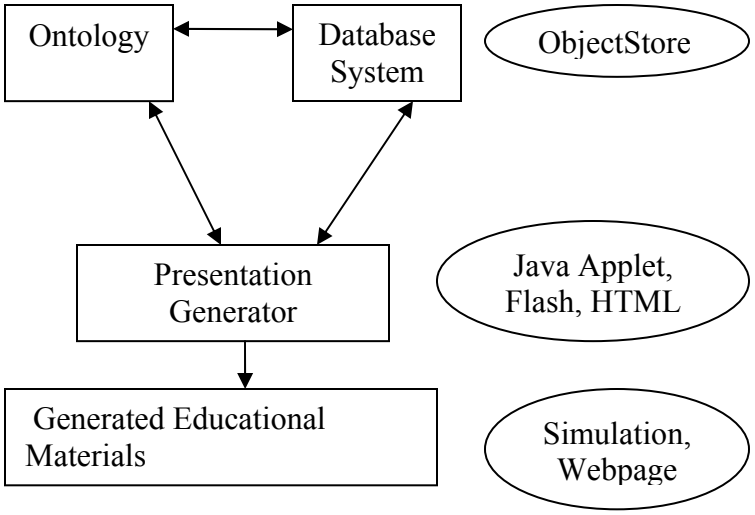

Figure 2-1. Components of a content management system used for developing educational materials -

Ontology

Each concept in the lab exercises is formally defined by a concept in the ontology. An ontology of the BMP lab exercise contains concepts such as bottle, stock solution (chemical), degradation, and other concepts specific to the lab. The BMP lab exercise uses many bottles so the ontology specifies the concept of bottle and stores various bottles (such as a bottle for storing samples) as a bottle concept. A concept contains taxonomic relationships (a "bottle" is a member of the class "equipment"), properties (a bottle has as a particular volume), and association with other concepts (a bottle can contain a chemical, a bottle can be physically connected to a valve). A concept or object can also have behavior (a bottle can fill or empty over time).

Methodology of developing an ontology

The ontology was developed using the Web Taxonomy authoring tool (described in section "Tools for Creating an Ontology"). The following elements were used in the ontology:

- Class: A class is used for describing general concepts like bottle or procedure. For example, the BMP lab exercise used many bottles & so a bottle class was used to describe the bottle concept.

- Individual: An individual is used for describing instances or specific occurrences of a concept class. For example, the BMP lab exercise used seven bottles so seven individuals of the bottle class were created.

- Property: A class can have several properties for defining its attributes. For example, radius and height were defined as a property of the bottle class for capturing geometrical information.

- Relationships: A class can have relationships with other classes. The relationship can be either predefined (subClass, superClass, hasParts, partOf) or user-defined (hasName or comesOutOf). The hierarchical relationships were modeled by subClass and superClass relationships. A bottle is a specific kind of equipment so there exists a relationship called "subClass" between the bottle class and the equipment class.

Ontology was developed with WebTaxonomy authoring tool. The following steps were used for developing the ontology:

- Collection of relevant documents: The relevant documents such as research papers, PowerPoint presentations, and published reports of ES CSTC projects were collected.

- Analysis of documents: The information from the relevant documents was analyzed and the concepts were extracted from them manually.

- Development of class hierarchy: The collected concepts were enumerated and classes were generated from the concepts. The classes were further organized into a class hierarchy by organizing classes from more general (like equipment) to the more specific (like pump). The classes were entered into the ontology using the Web Taxonomy editor. Figure 2-2 shows the class hierarchy for the BMP lab exercise created as a part of this project. Each class was specified by its definition, properties, and important relationships like superClass and subClass.

- Creation of individuals: The individuals were created by specifying the class to which the individual belongs and by entering the values of properties.

An individual of bottle class called “stock solution bottle 1” was created by following steps:

- Open the Web Taxonomy Editor (Figure 2-2).
- Specify the name of the class “bottle” to which the individual belongs-“stock solution bottle 1.”
- Create an individual using the Web Taxonomy editor
- Enter the definition of the individual and the values of properties for the individual (radius = 50, height = 10).

Tools for creating an ontology

Web Taxonomy (Beck and Lin, 2000) and ObjectEditor (Beck, 2003b) were used for creating ontologies. The availability of the ontology construction tools on the Web not only makes the tools more accessible and easier to distribute, it also allows users to collaborate over the Internet to develop educational resources. Web Taxonomy (Figure 2-2) is a tool for adding and editing the concepts in the ontology. Figure 2-2 shows a portion of the ontology developed for the BMP project, and it displays the different equipment items such as bottle, flask, gauge, etc. used in the BMP laboratory procedure. Each piece of equipment used in the experiment was described by an individual in the ontology. For example, the BMP lab used seven stock solution bottles so there are seven individuals of stock solution bottle in the ontology.

ObjectEditor (Figure 2-3) is an alternative graphic interface for partitioning the concepts that belong to a specific project like the BMP project. Figure 2-3 shows a portion of an ontology developed for the BMP project using ObjectEditor. In particular, this diagram (Figure 2-3) shows equipment objects and how they are physically connected. For example, it shows that the individual “ss pipe 1” is related to the

individual “stock-solution bottle 1” by a relationship called “out of bottle” because “ss pipe 1” comes out of “stock solution bottle 1”.

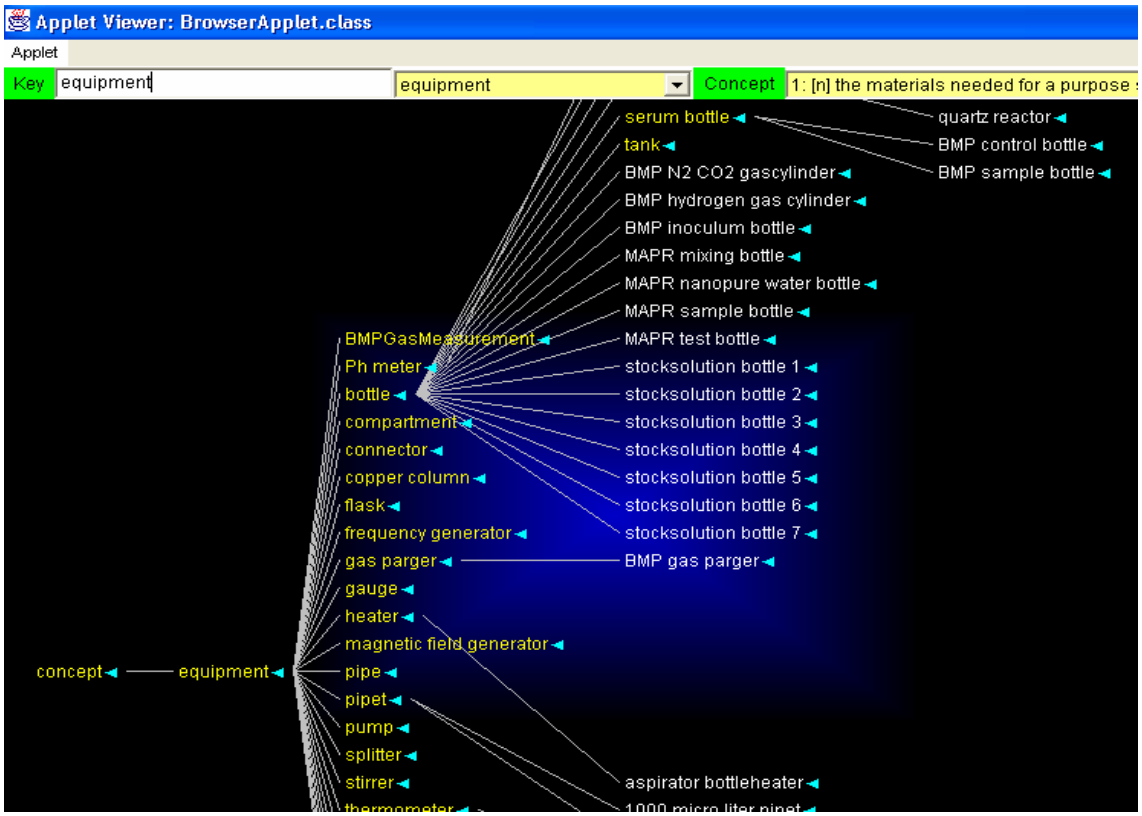

Figure 2-2. Schematic of Web Taxonomy showing a portion of the BMP ontology

The ontology captured not only the physical objects and their structural and dynamic relationships needed for developing interactive animations (educational simulations), but it also acts as a dictionary for all the terms used in the ES CSTC projects described in the section “Domains Studied”. The ontology provides a better way for students to browse concepts to learn their meaning and interrelationships. This dictionary provides machine-interpretable definitions, which means, the computer can analyze the meaning of terms, and provide reasoning facilities that can determine how

terms are related. A multilingual feature is also supported so that terms in different languages can be used to refer to the same object.

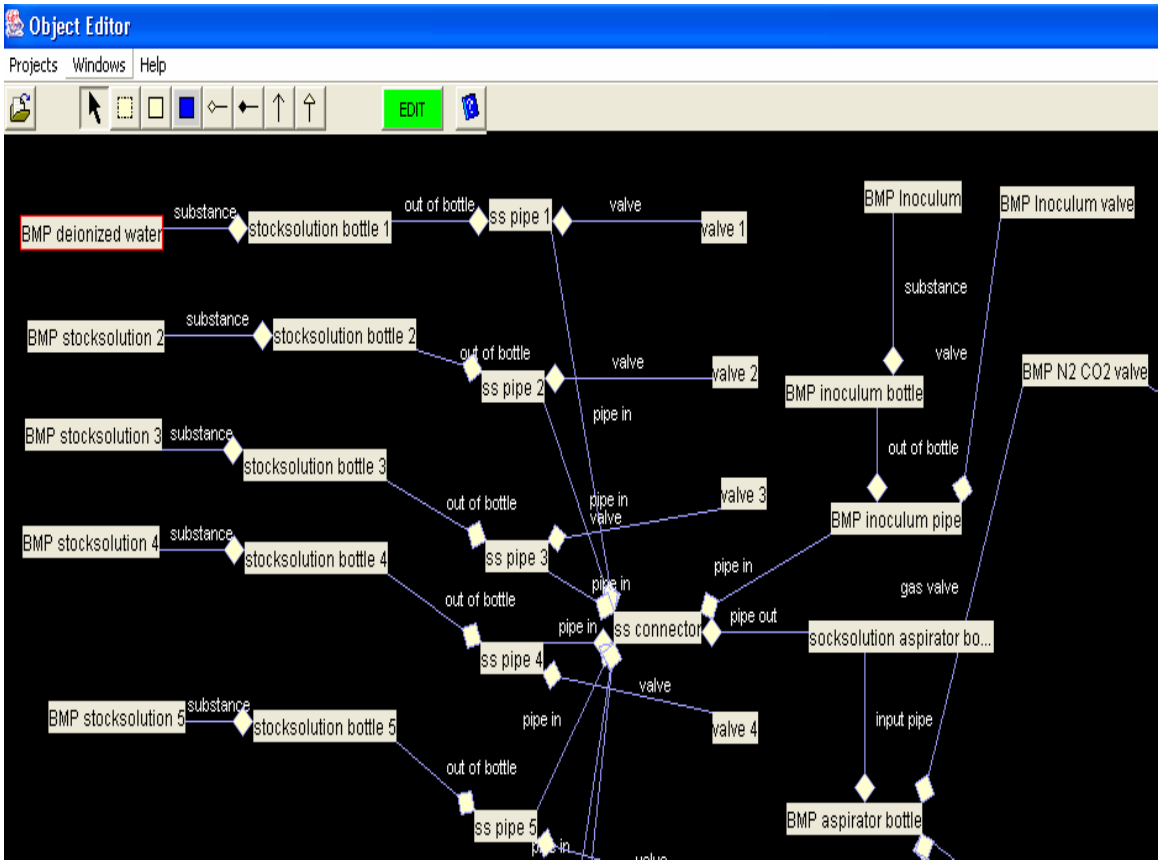

Figure 2-3. Schematic of Object Editor showing a list of equipment and reagents used in the BMP lab and the relationship between them

Database System

The web-based tools for constructing the ontology were built on top of ObjectStore (ObjectStore Website, 2006), a commercial object database management system. The object database was used for storing the ontology because the object database provided a more convenient and natural way to organize data structured as an ontology rather than through tables, as is done in a relational database. The integration of the web-based tools with a database facilitated the development of educational materials by storing the

ontology in the database and using it for generating educational materials in different formats.

The online tools allow the instructor to develop educational materials from any remote location and store them in a common server-side database. The concepts can be added or edited using Web Taxonomy, ObjectEditor, or other tools provided as part of the authoring environment (including equation editors, text, table, and vector graphic editors).

Presentation Generator

The presentation generator consisted of several computer programs written in various languages (Java, Java Server Pages (JSP)) for rendering educational material in multiple formats. Two applications were developed using JSP and Java applet technology. The JSP application was developed for rendering the research information of ES CSTC projects as a website while the Java applet application was developed for displaying the dynamic information of ES CSTC projects as educational simulations. The next sections describe these applications.

Java server page technique

The website for the projects at ES CSTC was generated using JSP technology. Figure 2-4 displays the interface of the website created for the BMP lab exercise, which shows the details of a chemical (stock solution) used in the BMP lab. A JSP is very much like a conventional HTML page and contains HTML tags for defining the appearance of a webpage, but it also contains additional tags embedded in the HTML that refer to database objects. In general, wherever a reference to a database object appears, the contents of that object are displayed at that point in the JSP. So, in Figure 2-4 the logos, titles, and frames were all created using static HTML tags, but the body of the text

was created dynamically from database objects referenced in the JSP. The JSP must be created manually, but then the content is inserted automatically. The following steps were used for creating the website from the content:

- Ontology development: The details of the ES CSTC projects (described in section "Domains Studied") were stored in the database by developing an ontology using the Web Taxonomy authoring tool. The process of developing an ontology is described in section "Methodology of Creating an Ontology".

- Design of website layout: The general layout of the website (logo, title, frames) was created in HTML using Microsoft FrontPage. Some of the links (e.g. "About the Center") on the left-hand side of the webpage were manually hyperlinked to an external website (www.ees.ufl.edu), while some of the links (e.g. "Project") were hyperlinked to the webpage generated from the content stored in object database.

- Development of JSP application: A JSP application was developed for rendering a specific concept in the ontology as an individual webpage. The JSP application contained the HTML tags developed during step 2 and additional tags for communicating with a Java class. The JSP application communicated with a Java class called "BMP Bean", and the "BMP Bean" class was used for communicating with the ontology database using Java Remote Method Invocation (RMI) protocol. Borland JBuilder integrated development environment (Borland Website, 2006) was used for developing the Java Bean class and for implementing the RMI protocol.

The presented approach illustrated an approach of dynamically generating a website from the ontology. The general layout of the website (header, side) was designed using Microsoft FrontPage. The content for the main body of the website was structured as an ontology, and the main body for the website was generated by the logic embedded in a Java class, as described in previous paragraph. The content for the main body of the website can be updated by modifying the ontology while the presentation of the website's main body can be changed by modifying the Java class.

It is easy to provide dynamic content using JSP (Sun Website, 2006). The JSP technology uses the functionality of Java language and is widely supporetd by the software vendors (Webber, 2000). The JSP technology uses reusable components, rather

than using only scripting in a page, which speeds up the development of an application (Sun Website, 2006). The JSP technology uses Java classes for generating the content of a webpage and HTML tags for controlling the layout of the webpage. In this way, the JSP seprates the content and layout of a webpage. Java IDE tools can be used for debugging Java classes while the commonly used webpage design tool can be used for debugging the html part of the JSP website.

The functioning of JSP involves the generation of a Java class from the JSP and the Java class is then parsed to create a servlet class (Webber, 2000). Another disadvantage of the JSP technology is that the content and the logic is not well separated. The JSP technology allows the embedding of logic in a webpage, which defeats the purpose of separating the logic and the content (Spielman, 2001). This can create the problem of maintaining and updating the website. The JSP technology also allows the insertion of inline Java code in a JSP page, which makes it difficult to separate the tasks. This also creates the problems in understanding the JSP page.

Java applet technology

The Java applet described in chapter 3 was used for presenting dynamic information of the ES CSTC projects. The presentation of dynamic information required interactive features provided by the Java applet technology. In contrast, the JSP technology is used for generating HTML, XML or other types of documents. This study used JSP for generating HTML. However, Java Applets can be inserted in a JSP page for providing interactivity.

Generated Educational Materials

The educational materials were generated from the same database in two formats: as a website containing text and graphics and as an educational simulations. The website

was used to display the ontology of the ES CSTC projects in solid waste treatment and wastewater treatment. Students can browse the different waste treatment concepts and use the website as a waste management dictionary. The educational simulation (described in chapter 3) is a Java applet that presents the dynamic information as a 2-D animation. The simulations were evaluated in two courses taught in University of Florida.

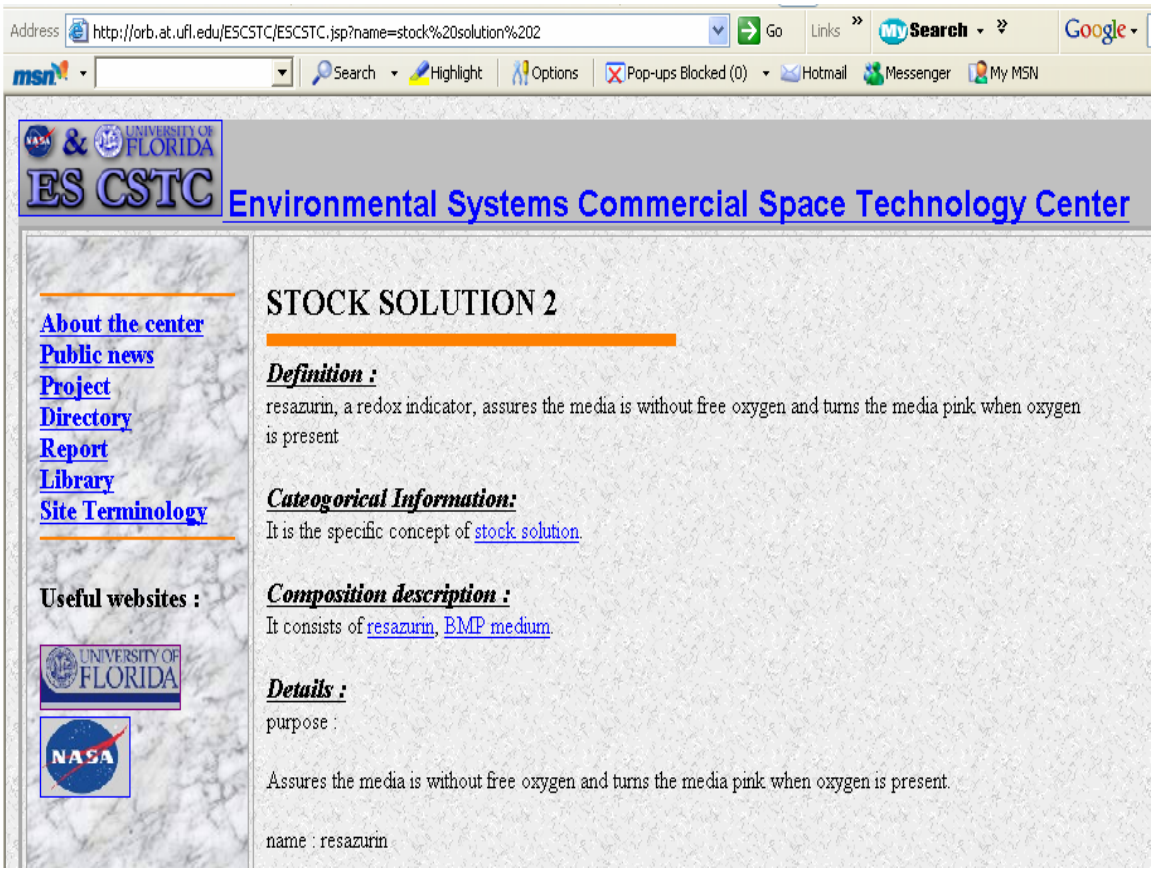

Figure 2-4. Website generated by the content management approach

This study showed that the content management approach (i.e., using a database to store research information) can be used for documenting research information. The information was first structured as an ontology (structured information) and stored inside

an object database (an ontology management system). This approach allowed the documentation of research at a very fine level (i.e., documenting research at the level of concepts used in various research projects) instead of storing the educational materials at only a course level in the form of documents, presentations or other formats that fail to explicitly represent content. There can be an overlap of concepts used in various projects, and the overlap of concepts can be used for identifying similarities in various projects. For example, both SEBAC and BMP project uses the concept of anaerobic digestion, so the overlap of concepts in ontology can infer the similarity in BMP and SEBAC project.

The JSP technology was used to generate a website from the ontology. Automatic presentation techniques can greatly reduce the effort required to create educational materials; however, it is not always desirable to fully automate the process, as often the instructor does want to have full control over the presentation. Chapter 3 describes the automatic generation of educational simulation (rendered as a Java applet) for displaying dynamic information of the lab processes used in the ES CSTC projects. Information about the lab processes was stored in the ontology and the dynamic information was displayed in an interactive format – animations – using Java applet technology.

CHAPTER 3
EDUCATIONAL SIMULATION: AN APPROACH FOR PRESENTING DYNAMIC INFORMATION OF A PROCESS

Introduction

It is critical to present educational materials in a format that best matches the student's individual needs. Since engineering processes are dynamic in nature, it is beneficial to present the processes in the form of an educational simulation. An educational simulation is a presentation of a dynamic process (like the steps of a laboratory experiment or operating a machine) as an interactive and intuitive animation which can help a student in understanding a specific process. The interactivity of the educational simulation increases a student's learning efficiency (Mclean and Riddick, 2004). Another advantage of using simulation is that the student can access it anytime and anywhere, in contrast to an in-lab experience requiring special equipment.

Virtual Lab

Educational simulations are also known as virtual labs, where students can experiment with the equipment and the process itself. Instructors can show the lab in the form of an animation for explaining the different concepts in the lab. The learners can also change the process parameters to study how they impact the behavior of the system. Since one of the objectives of this project is to present information in a format most suitable to students, virtual labs have been created for explaining the concepts of waste treatment processes described in Chapter 2.

Literature Review on Virtual Labs and Educational Simulations

Virtual laboratories have been developed in various domains like physics, engineering, power electronics, and medicine (Hashemi, 2005). The IrYdium project developed educational materials in the domain of chemistry (Yaron, 2003). Their goal was to create a simulation-based learning environment where high school and college students can learn the concepts of chemistry through interesting real-world applications. Remote database and network technologies were being used to facilitate the delivery of the software over the Web. Similarly, a multimedia-based course in environmental engineering and process design was developed at University of Maine (Katz et al., 1997). The video clips and spreadsheet technologies were used for explaining the processes of natural systems as well as data collection processes. A virtual laboratory in the area of material science and engineering was developed in the Department of Mechanical Engineering at Texas Tech University using Flash and other multimedia technology (Hashemi, 2005). The University of Florida used the same approach (Flash technology) in the domain of medicine to teach an anesthesia machine operation (Lampotang, 2004).

The University of California, Davis developed seventeen virtual experiments in food processing for academic purposes (Singh and Erdogdu, 2005). Each virtual experiment includes simulations, which were implemented with Flash technology. These simulations were developed for enhancing the understanding of engineering concepts used in food processing operations.

Rice University is using Java technology for teaching various statistical concepts (Lane, 2003). The Iowa Bioprocess training center offers training in bioprocessing by virtual reality and classroom training (Brigham, 2003). Because of the cost and skills requirements, there is a great need for training bioprocessing (waste management) skills

by simulations or virtual laboratory. Many other examples of teaching a concept by utilizing a virtual laboratory are also available on the Web.

The task of creating a virtual laboratory is challenging because it requires a multidisciplinary effort; in addition the task of managing the content of virtual laboratory becomes more challenging as the content increases in volume and complexity. Most of the virtual laboratories are implemented using a conventional programming language (JAVA, C, ActionScript) and software tools with little effort in explicitly representing content. This study investigated an approach of using an ontology for structuring and storing the content for facilitating the development of virtual laboratories and other educational resources.

Methodology of Creating Educational Simulations

The content management approach described in chapter 2 was used as a methodology for creating educational simulations. These simulations were developed for running the experiments related to the waste treatment processes, as described in chapter 1, on the Web. The following steps were used for creating educational simulations:

Ontology Development

The details of an experiment were stored in the database by developing an ontology using the ontology development tools described in chapter 2. The ontology was developed for a specific domain like the BMP lab exercise. The details of the lab exercise like information about various equipment (bottles, pipes, valves), chemicals (stock solutions, inoculums), and samples used in the experiment were represented as different individuals in ontology. The information of the lab exercise was structured using the concepts of object-oriented design and ontology principles. For example, “paper” is a kind of a sample and it has a property called “rate constant” with a value of

"2 seconds" which was used for calculating the rate of degradation for biodegradable sample. Therefore, a concept called "sample" was entered in the ontology and "paper" was described as a specific type (or subclass) of sample. Each paper concept has a property called "rate constant" used for storing the value of rate constant.

Development of Java Classes

Java classes were developed for rendering the details of specific concepts (like equipment) used in the lab exercise and also for implementing the behavior of specific concepts (like bottle) in the simulation. The details of the concepts were stored in the ontology. For example, a bottle is a concept that has width and height. The details of the bottle and its association with different concepts were stored in the ontology, but Java classes were implemented for rendering the bottle concept and required behavior like filling and emptying the bottle. A Java class was implemented for every physical individual in the simulation, and within each Java class, methods implement the behavior of each individual.

Development of Educational Simulation

The simulation was rendered as a Java applet. Individuals specific to a lab exercise were loaded into a module using Object Editor (described in chapter 2). The applet loaded the details of each individual (equipment) in the module from the ontology and executed corresponding Java classes for rendering the details and behavior of each equipment. The simulation was implemented in two modes: movie mode and interactive mode. Movie mode (Figure 3-1) was implemented by writing a script which was used for starting and stopping the animation of different equipment. The movie mode ran the

simulation sequentially, similar to the instructions or standard operating procedure for a process, so a student can get an overview of the process.

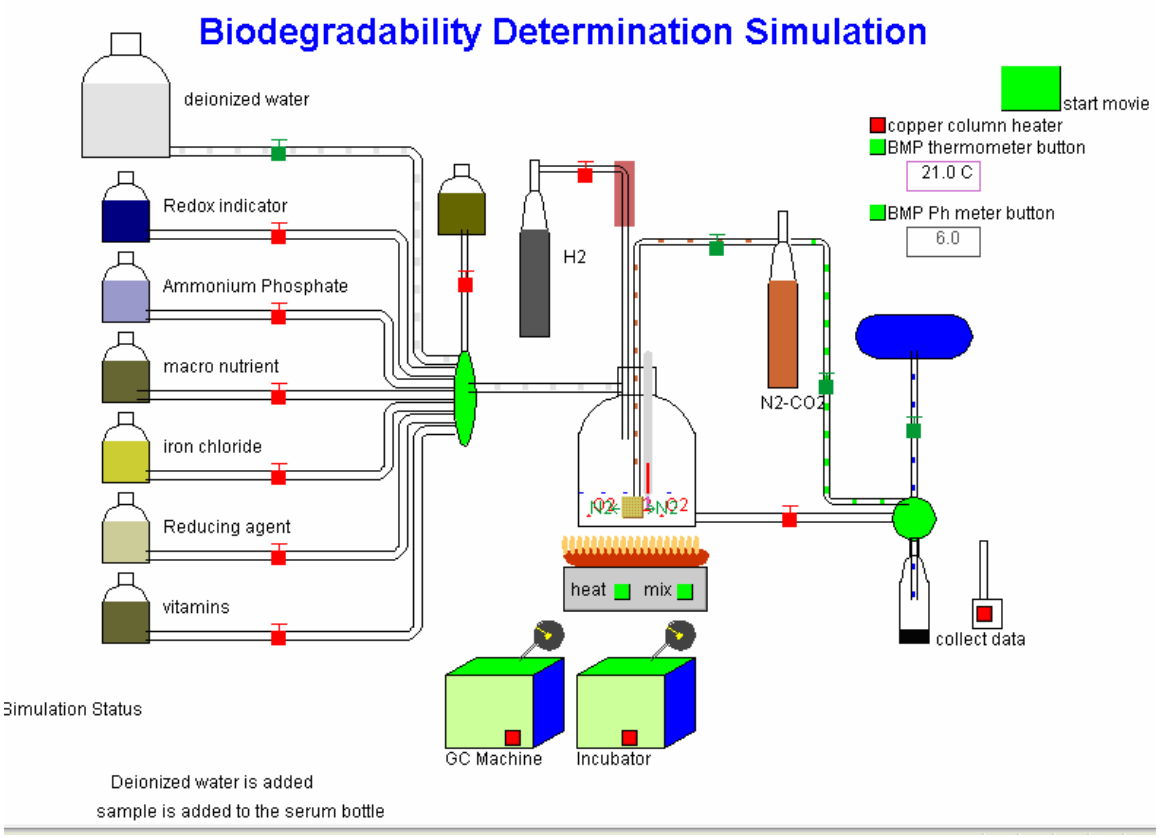

Figure 3-1. Interface for the BMP laboratory for determining biodegradability of a sample in movie mode

Interactive mode (Figure 3-2) allowed students to experiment with the lab experiment in an interactive fashion. In the interactive mode, the learners started and stopped the animation of different equipment by clicking on the valves and buttons (Badal et al., 2004c). The instructions for running the simulation in interactive mode are given on the ES CSTC education and outreach website (ES CSTC Education and Outreach Website, 2006).

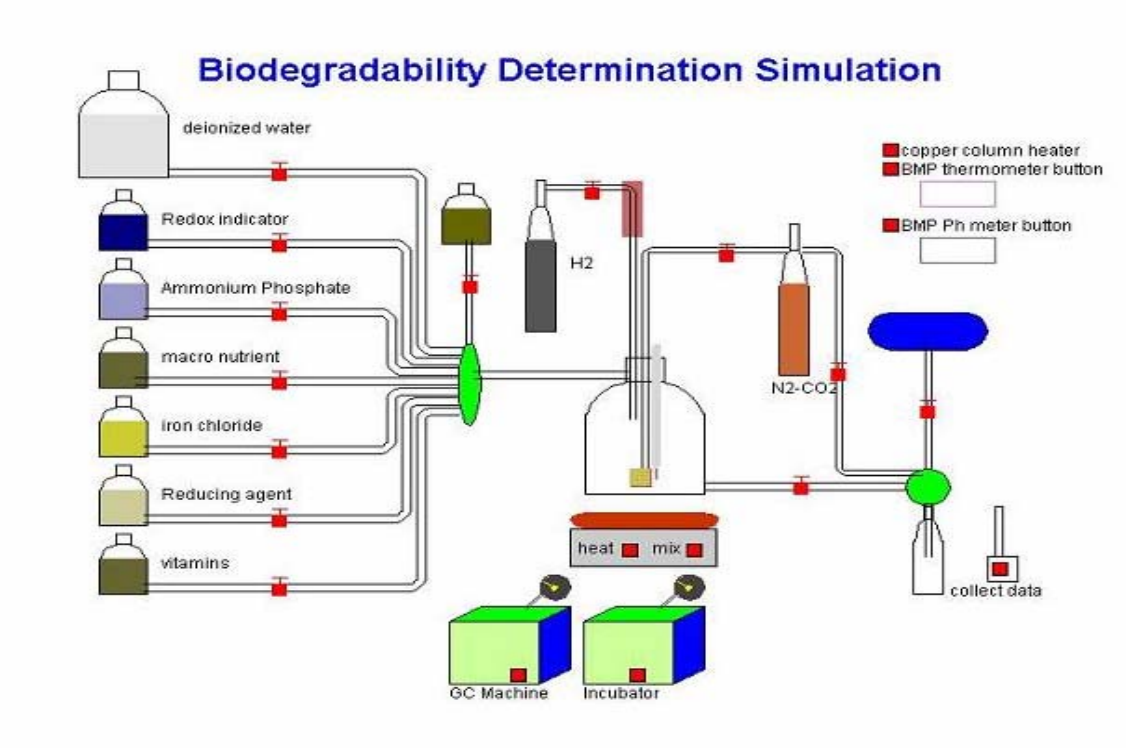

Figure 3-2. Interface for the BMP laboratory for determining biodegradability of a sample in interactive mode

Results

Several educational simulations were developed for explaining the different aspects of waste treatment processes. The details of these processes are described in the "Domain Studied" section of chapter 2. These simulations can be accessed from the ES CSTC education and outreach website (ES CSTC Education and Outreach Website, 2006)

Simulation for Solid Waste Treatment

Bioprocess lab (BMP lab)

Figure 3-1 and Figure 3-2 show the interface for the BMP laboratory exercise for determining biodegradability of a sample in movie mode and interactive mode. Figure 3-1 shows that the BMP lab exercise contains nine bottles, one reactor, two gas cylinders,

one gas chromatography equipment, and one incubator. The BMP process involved mixing, heating, and cooling of chemicals to prepare a medium. The sample and medium were mixed and placed in an incubator. The biodegradability was measured after one, three, five, fifteen, and thirty days by the gas chromatography equipment.

SEBAC simulation

Figure 3-3 shows the interface of the SEBAC process for treating solid waste in the movie mode. It shows five reactors that were used for various purposes (filling sample, empty sample, and storing new, activated (matured), and old sample) during the SEBAC process. The sample was treated in the reactors by circulating a new sample with an old sample and by circulating the activated sample with itself. The movie mode (Figure 3-3) shows three buttons which can be clicked for showing the different circulations in the SEBAC process. The "single reactor" button shows the circulation in the reactor containing the activated sample. The "two reactor circulation" button shows the circulation between the reactor containing the old sample and the new sample. The "three reactor circulation" button shows the circulation between the reactor containing the old sample and the new sample and the circulation in the reactor containing the activated sample. Figure 3-4 shows the interface for the SEBAC process for treating solid waste in interactive mode. The user can click on different valves for activating the flow in the pipe and filling the reactor.

The interface of the SEBAC process (Figure 3-3, Figure 3-4) has many pipes, reactors, and valves which can be hard to comprehend, so an additional simulation was developed for showing the circulations between the three reactors in the SEBAC process (Figure 3-5). The simulation shows three reactors with new, activated, and old feeds.

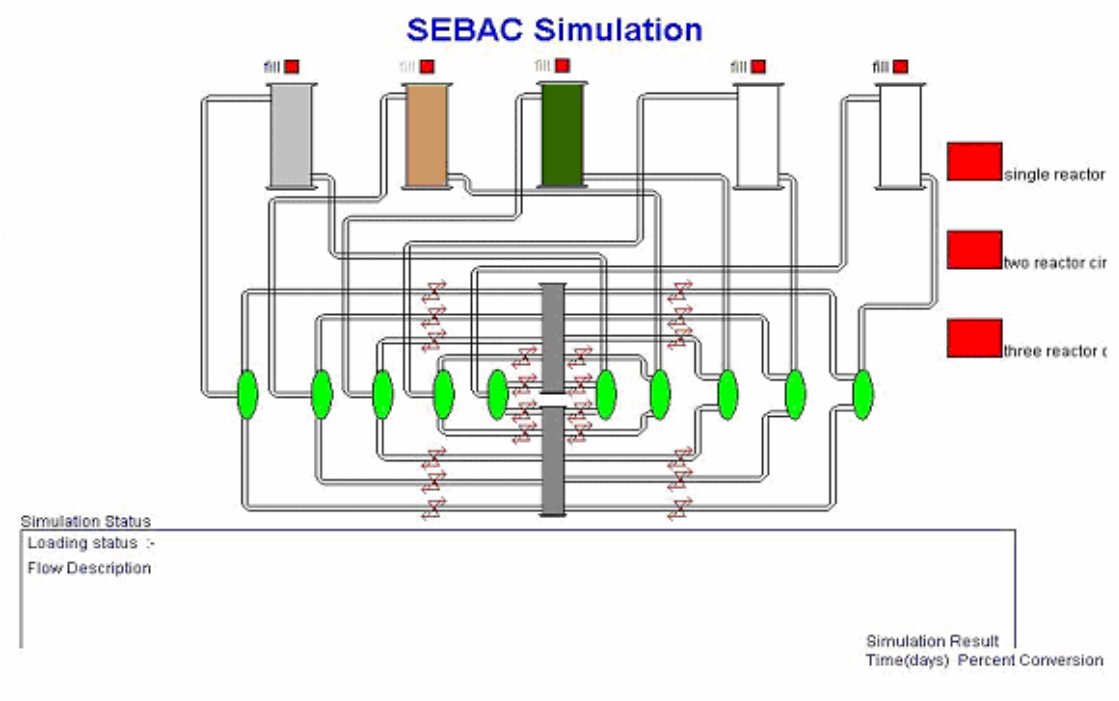

Figure 3-3. Interface of the SEBAC process for treating solid waste in movie mode.

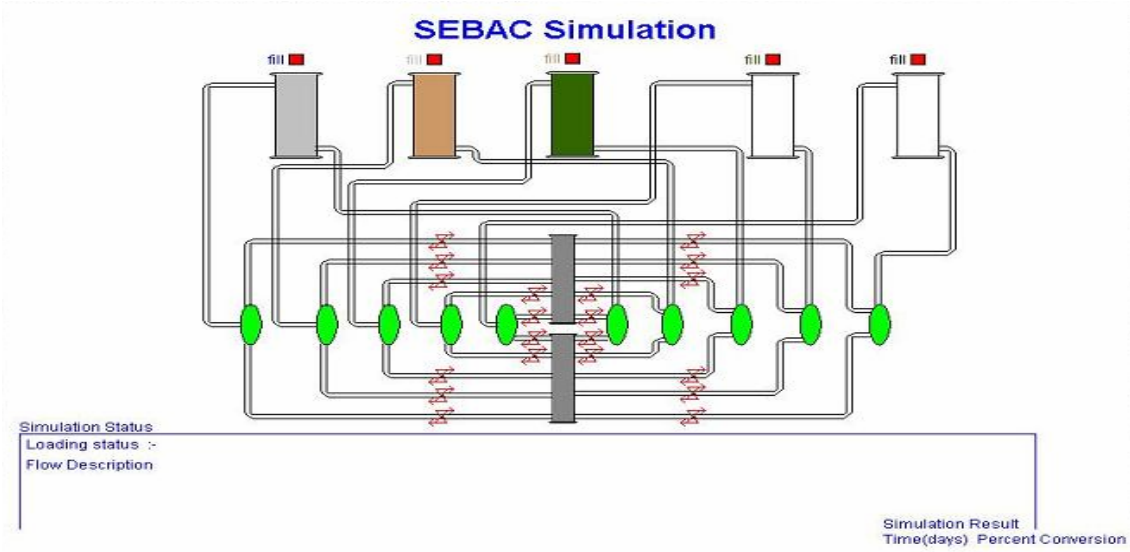

Figure 3-4. Interface of the SEBAC process for treating solid waste in interactive mode

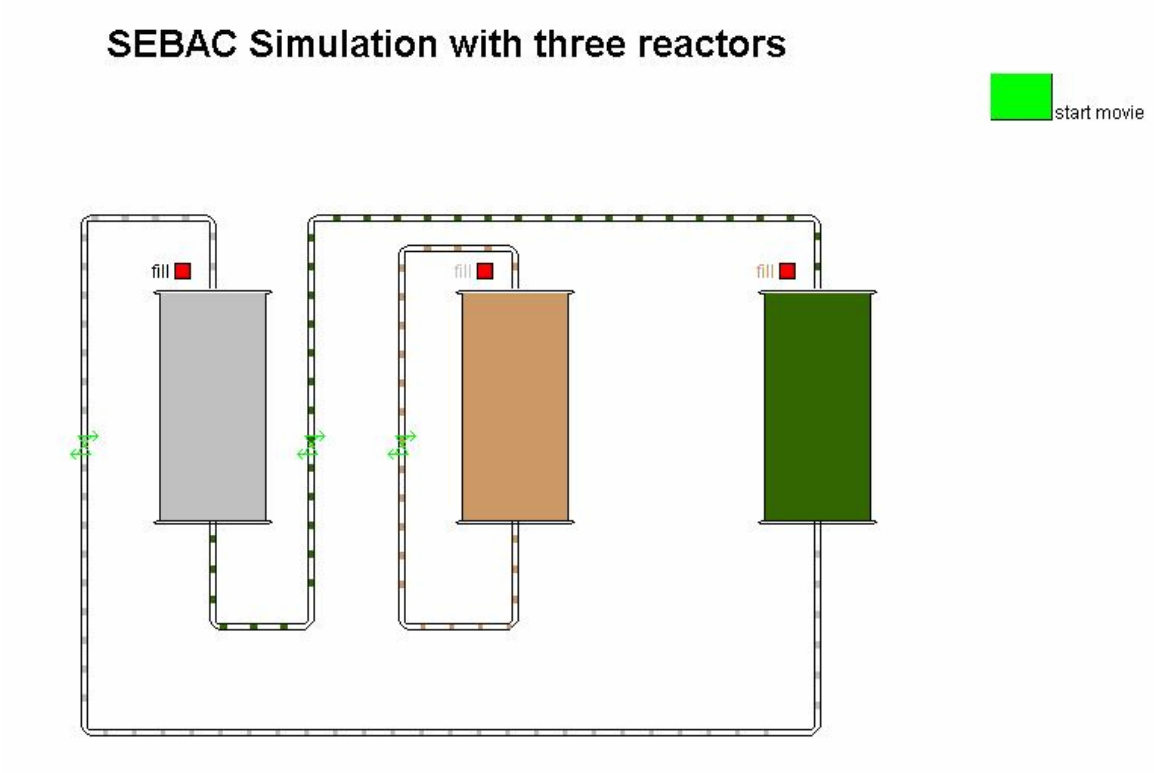

Figure 3-5. Interface of the SEBAC process with three reactors for treating solid waste in movie mode (ES CSTC Education and Outreach Website, 2006)

It does not show the process of filling and emptying the sample in order to simplify the presentation. Figure 3-6 shows the phenomenon of clogging in the SEBAC process. The clogging simulation was developed in an interactive mode. The student can click the two-way valve for circulating the flow of liquid slurry (leachate) in an up-flow direction or down-flow direction. The simulation illustrates the movement of solid sample particles in the reactor and the flow of leachate in the reactor and the pipe. The pressure of the reactor is shown by the pressure gauge. The pressure in the reactor increases due to the accumulation of solid particles (that is, clogging) at the inlet and outlet of the reactor. The problem of clogging was solved by reversing the flow of leachate. The reversible flow of leachate was achieved by using a two-way valve. The flow should be reversed automatically or manually after a fixed time to avoid clogging. In Figure 3-6,

up-flow is obtained by clicking the upper half of the valve and the down-flow is obtained by clicking the lower half of the valve.

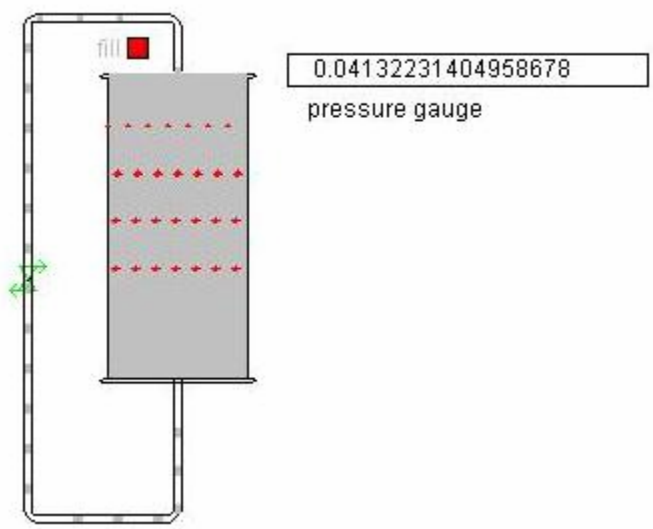

Figure 3-6. Interface of the SEBAC process with a single reactor for showing the process of clogging (ES CSTC Education and Outreach Website, 2006)

Simulation for Wastewater Treatment

Figure 3-7 shows the interface of the MAPR process for treating a sample of wastewater in movie mode. The user can watch the MAPR process by clicking the "start movie" button. The interface shows two bottles for storing a wastewater sample and nano pure water. These bottles were connected to the third bottle (mixing bottle) by pipes which have valves for moving the wastewater and nano pure water to the mixing bottle. The color of the valve changes to green when the valve is opened, and the color changes to red when the valve is closed. The wastewater sample and nano pure water were mixed in the mixing bottle. The diluted wastewater sample was treated in the MAPR reactor in the presence of ultraviolet (UV) light and a magnetic field. The UV light lamps were used for producing UV light. A frequency generator was used for generating electrical signals at three different frequencies. These electrical signals were

transmitted to a solenoid for producing a magnetic field. The treated wastewater sample was sent to the spectrophotometer for the analysis of wastewater.

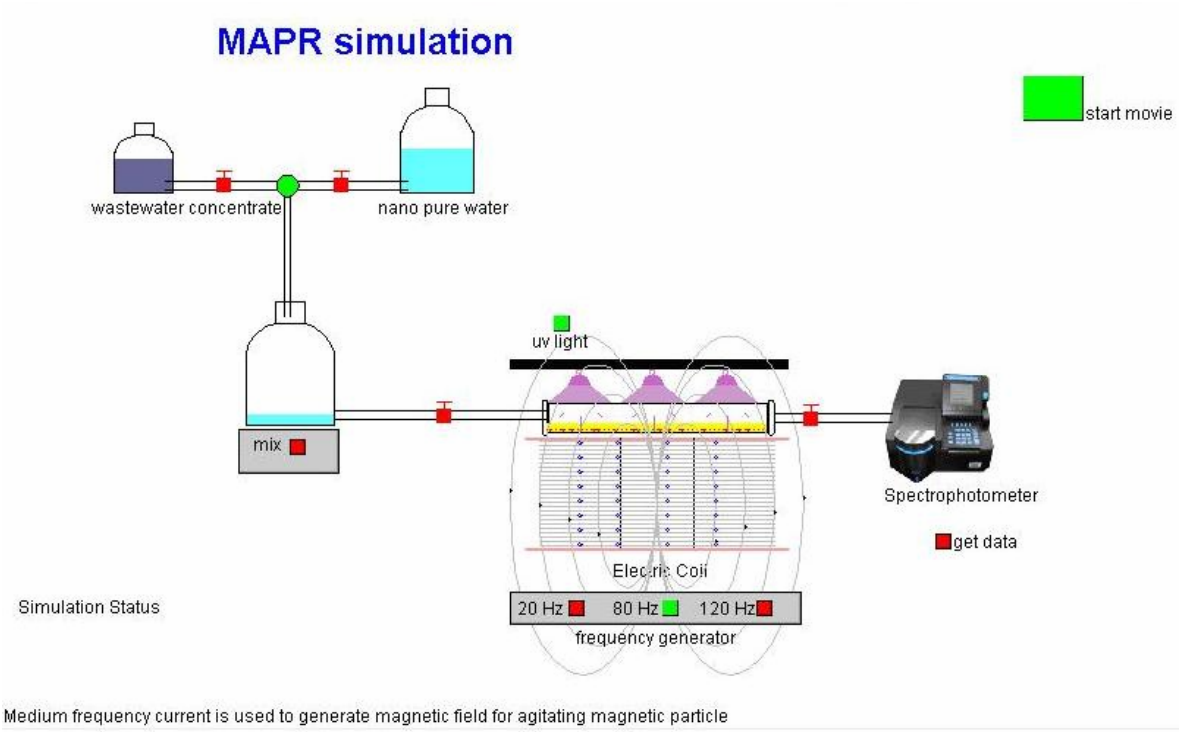

Figure 3-7. Interface of the MAPR laboratory for treating a sample of wastewater in movie mode

The user can click on valves and buttons for running the MAPR process in an interactive fashion. Figure 3-8 shows the interface of MAPR laboratory for treating a sample of wastewater in interactive mode.

Evaluation of Simulation

Evaluation of Solid Waste Treatment Simulation

An evaluation of the BMP lab exercise was done with the objective of collecting feedback from students and to compare the methodology of teaching the BMP lab exercise by simulation with the conventional lab instructions and hands-on methods. An evaluation form was designed to measure the understanding of technical concepts by the students as well as their perspective about the teaching methodology.

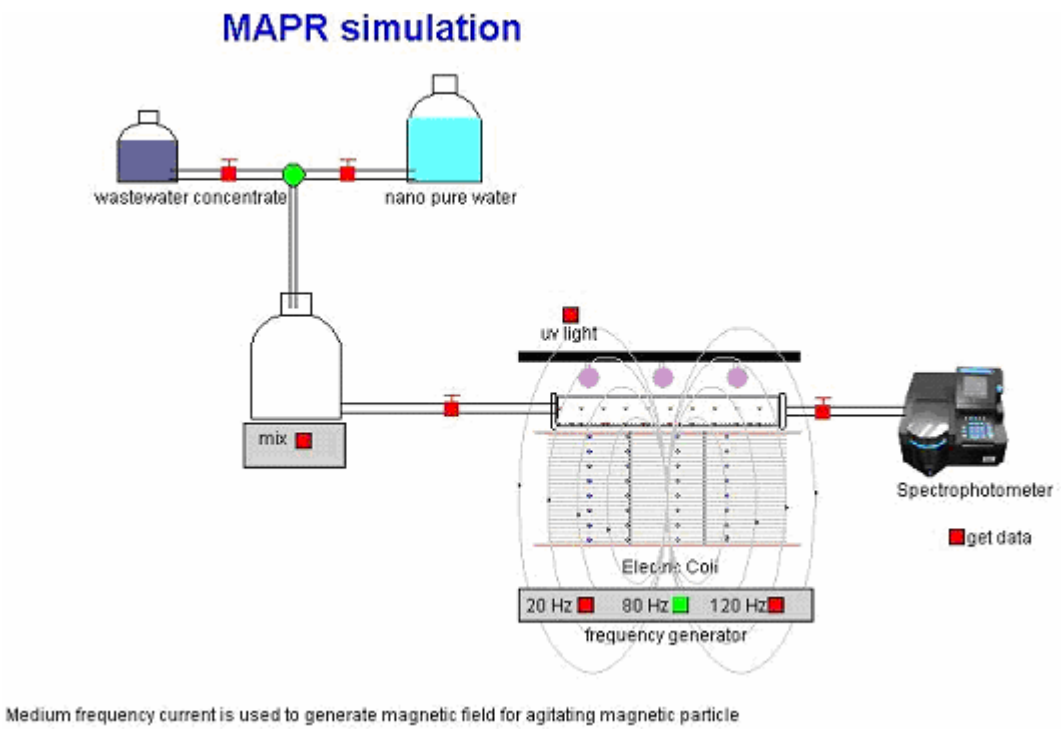

Figure 3-8. Interface of MAPR laboratory for treating a sample of wastewater in interactive model

The understanding of technical concepts was measured by designing a set of ten questions related to the BMP lab exercise with the help of the instructor, Dr. John Owens. The perspective of the students was measured by designing a set of eight questions related to the experience of the students with the teaching methodology. The subjective evaluation measured the following aspects:

- Encouraging students to learn by a particular teaching methodology
- Developing confidence in the students about concepts used in the lab
- Enabling students to work through course materials at their own pace
- Developing students' creativity and skills
- Enabling students to apply the concepts learned in the lab to real world situations
- Teaching students to work together

The students were also asked if they found the teaching methodology interactive and if they had a good learning experience during the evaluation. These questions were in the format of multiple choice.

Figure 3-9. Overall subjective experience of the students by two teaching methodologies for the BMP lab evaluation

Ten students of ABE 3062 (Course Website for Bio. Eng. Lab, 2004) were asked to read the lab instructions and perform the lab manually. After performing the lab, the students were asked to fill out the evaluation form (Appendix A) within one week. Seven students of ABE 4666/ABE 6663 were shown the simulation as a group and were asked to complete the evaluation form in the classroom. Before evaluating the simulation, the students of ABE 4666/ABE 6663 were given a brief tour (45 days before seeing the simulation) of the BMP lab as a part of the course.

Results of the evaluation were that the average score (technical concepts) for the class after seeing the simulation was 57.14, and the average score for the class after

reading the lab handout and performing the lab was 62.22. The statistical analysis showed that there was no significant difference in the scores ($t = -.5$, $df = 14$, $p = .25$).

The subjective evaluation (Figure 3.9) showed that students found both teaching methods (hands on lab and learning by simulation) useful to nearly the same extent. The results showed no significant difference in the various aspects of subjective evaluation except that the students found it easier to work at their own pace with the conventional method than by simulation. Of course, in this evaluation the students were not yet given the chance to use the simulation individually; rather, the instructor showed the simulation to the entire group.

Evaluation of Wastewater Treatment Simulation

The class of ENV 4514 (Water and Wastewater Treatment) was divided into two groups. Each group had seventeen students. The first group was asked to run the simulation on their laptop and read the online lesson. The online lesson was designed manually using Microsoft FrontPage for giving the background information of MAPR process. Some of the concepts in the online lesson were linked to the MAPR ontology. The students were asked to complete the evaluation form (Appendix B) after running the simulation and reading the online lesson. Presently, the students are not given the hands on experience using the MAPR process because the lab exercise has not been designed. The second half of the class attended the class room lecture of MAPR and was asked to fill the evaluation form in the classroom.

Results of the evaluation showed that the average score (technical concepts) of the class after performing the simulation was 82 and the average score for the class after attending the class room lecture of MAPR was 73. The statistical analysis showed that

there was no significant difference in the score (t =1.59, df = 16, alpha = .05) for technical concepts.

The results showed the significant difference in the following aspects of subjective evaluation:

- The confidence in the concepts of the MAPR lab after performing simulation was greater compared to learning the concepts in the classroom lecture (t = 2.51, alpha = 0.05).
- The simulations enabled students to work through course materials at their own pace (t = 4.4, alpha = 0.05).
- Students found the learning experience with simulation more interactive (t = 2.79, alpha = 0.05).
- Students did not like the learning experience with simulation (t = -2.66, alpha = 0.05).

However, the results also showed that there was no significant difference in the following aspects of subjective evaluation:

- Encouraging students to learn by a particular teaching methodology
- Developing students' creativity and skills
- Enabling students to apply the concepts learned in the lab to real world situations

Conclusions

Based on the results of evaluation, it can be concluded that the simulation can help the instructor in teaching a lab exercise. The effectiveness of simulations also depends on the approach of integrating simulations in the instruction, that is, the simulations can be either shown to the students as a demonstration or students can run the simulations on their own computer. The evaluation results concluded that the simulations enabled students to work through course materials at their own pace when the students ran simulations on their computer whereas the students were not able to follow the concepts when the simulations were only demonstrated in the classroom. In addition, the

confidence of a student in the lab concepts increased when the student ran the simulation on his/her computer.

The use of simulation helps in teaching the lab where it is practically infeasible to teach the lab as a hands-on approach because of the high cost of the equipment and chemicals involved. Simulations can also serve as a replacement experience for universities and colleges that do not have a waste treatment laboratory. The computer-based simulation can also be used to augment the real laboratory experience. Furthermore, the techniques presented in this study can reduce the cost of creating computer-based simulation.

The evaluations were not designed by consulting the statistical analysis professionals. However, instructor of BMP lab (Dr. John Owen) and instructor of the MAPR lecture (Dr. Dave Mayzyck) were consulted for developing evaluation forms, and they are consistent with the type of evaluations (tests and quizzes) used in the courses taught by these instructors.

CHAPTER 4
AN ONTOLOGY-BASED APPROACH TO MATHEMATICAL MODELING

Introduction

An ontology-based approach to mathematical modeling, in which a model is represented using ontology concepts, can help address several problems with current methodology used to develop simulations. The general goal is to better communicate knowledge about models, model elements, and data sources among different modelers and between different computers. This can be achieved through the ontology's ability to explicitly represent and thus define concepts used in models.

Various researchers create simulations within a particular domain to address a specific problem. For example, various simulations have been written in the domain of solid waste management for determining anaerobic biodegradability of a solid waste (Batstone, 2002). There is an overlap of the concepts and interactions used in these simulations. Frequently, different modelers use different symbols for the same concept. The use of different programming languages makes communication even more difficult (Reitsma and Albrecht, 2005).

Literature Review

Problems in Developing Simulations

Typically, a model is implemented in a particular programming language like FORTRAN, C++, or Java so it can be run to understand the behavior of the system. However, the meaning of the model is lost when it is represented using program code (Furmento et al., 2001). Researchers must understand the programming language in

order to understand the model. Semantic issues (like meaning of symbols or concepts used in the model) should be addressed so the knowledge in a simulation can be made explicit (Lacy and Gerber, 2004). While such models are documented using papers and manuals, this documentation is physically separate from the model implementation itself. It is difficult to maintain both the model and the documentation, and often the documentation is not an accurate description of the model implementation. All the details of program code are difficult to describe in written documentation, so that ultimately it is necessary to read the computer code in order to truly understand how the model works. These issues need to be addressed so the knowledge in a simulation can be made explicit (Lacy and Gerber, 2004; Cuske et al., 2005).

Typically, many different yet similar models are available for a particular domain like solid waste management (Batstone, 2002). The challenge lies in knowing precisely how two models are similar or different and selecting the one most suitable for a particular task (Yang and Marquardt, 2004). When a particular model is encoded in a conventional programming language, it is very difficult to do comparisons between models.

The construction of a model starts by problem definition followed by the development of a conceptual model, mathematical model and the implementation of mathematical model. Initially, the problem is defined as a text or other suitable format. Once the problem is made explicit then the task of conceptualizing the problem takes place. There are different ways to conceptualize a problem (Fishwick, 1995). The conceptual model defines the structure of the problem and characterizes a system using physiochemical concepts (Yang and Marquardt, 2004), that is, it represents a system as a

network of concepts. For example, a conceptual model of a solid waste treatment process consists of various concepts like bacteria, fatty acids, ions, and interrelations such as conversion of acids into ions (Lai, 2001). These concepts and interrelations are further represented as mathematical symbols and equations within a mathematical model. A mathematical model is further implemented as a simulation. Different tools and vocabulary are used in development of each layer (conceptual, mathematical, simulation code) of the model (Zerr, 2005). As the model incorporates new functionalities, the modifications are not made in all layers of the model. For example, the simulation is often modified to incorporate the new system functionality by modifying the code, but the conceptual model is not updated (Zerr, 2005).

Possible Solution for Communicating Knowledge of a Model

One of the possible solutions for enhancing the communication of knowledge about models at both the researcher/developer and machine level is the use of ontologies. An ontology is an explicit specification of a conceptualization (Noy et al., 2000). An ontology contains a set of concepts within a particular domain and shows how the concepts are interrelated. One of the uses of ontologies is management of knowledge. Simulations are used for studying a particular system like a waste management system. They contain knowledge about a specific process in a particular domain. A simulation in the area of solid waste management contains concepts like bacteria, solid waste, and acetic acids.

Utilizing ontologies for managing model and simulation knowledge facilitates representing this knowledge in an explicit manner. An ontology provides the model semantics, which allows a computer to interpret concepts in an automated manner (Lacy and Gerber, 2004). The construction of ontologies encourages the development of

conceptually sound models, more effectively communicates these models, enhances interoperability between different models, and increases the reusability and sharing of model components (Reitsma and Albrecht, 2005). It also provides assistance in computation by structuring data (Altman et al., 1999).

Web Ontology Language, OWL (OWL, 2005), can be used for describing the ontology of a solid waste management process called Sequential Batch Anaerobic Composting (SEBAC). The Owl:Class is used for describing generic concepts like bacteria while the specific instances like propionate bacteria are modeled as the Owl: Individual. The Owl:Property is used to define a property of a concept. Two types of properties have been used to model the relationships. The Owl:ObjectProperty models relationships between individuals while Owl:DataTypeProperty models relationship between individuals and data values. Each property has a domain and range. For example, the concept bacteria has a property called "acts on" which is used to describe the interaction of bacteria with fatty acids. The "acts on" property is defined with bacteria class as domain and fatty acid class as range..

Applications of Ontologies in Simulation

The notion of combining ontologies with simulation has received much attention in recent years (Fishwick and Miller, 2004; Lacy and Gerber, 2004; Miller et al., 2004; Raubal and Kuhn, 2004). This section explores several different ways in which ontologies can be applied to simulation, and in particular how ontologies can solve some problems in current methods of building simulations for agriculture and natural resources.

Model base

Many biochemical and physiochemical processes in waste management are fundamental and well studied. For example, anaerobic digestion process has been studied

and used for treating wastewater and solid waste. Many different anaerobic digestion models have been built over the years, but their uses by engineers, waste management operators, and process technology providers has been very limited (Batstone, 2002). The International Water Institute has established an anaerobic digestion modeling task group for developing a generalized anaerobic digestion model for achieving extended usage of anaerobic process knowledge generated by research activities and operational experience. The development of such a generalized model has many advantages. It will increase the application of models for plant design, operation, and optimization. The common vocabulary in the form of a general model will also facilitate future model development and transfer of technology from research to industry.

Similarly, there are many crop models, but there is no comprehensive management system for managing all these models. Research is being done to develop a suite of crop models for a variety of crops and integrate these crop models with weeds and insects models (Agriculture Research Service, 2005). Many other crops can be modeled by assembling modules from available models and changing few parameters and rate equations. However, having so many different yet similar models causes problems in managing models and in sharing model components among developers. There is unnecessary redundancy resulting from poor communication among developers. For example, there may be as many as two dozen irrigation models that all basically operate on the principles of water balance. They may use similar ways of calculating processes such as evapotranspiration, or they may use different equations to achieve the same results. Unfortunately, the traditional methods for creating these models make it very difficult to compare the models to see how they are similar or different.

An ontology can be used to build a database of models, that is, a “model base”, that can help to classify different but similar models and that can be searched to locate models and model components suitable for a particular application. Each specific model can be represented by an instance in the ontology and abstract model structure and behaviors represented as classes. Similar models can be grouped together into a class, and neighboring related classes grouped together to form subclasses. At the top of the resulting taxonomy would be generic modeling approaches. If an ontology is also used to represent the internal structure of a model, then model internals can be compared in an automated fashion to determine which parts of the model are similar and which are different.

The vast collection of models and model components resulting from this analysis would create a large but organized taxonomy. This taxonomy could be searched using query processors based on ontology reasoners (as explained in section “Reasoning”) to locate models (and model components) of interest. It can also be used to compare and contrast two models and explicitly identify how they are different or similar.

System structure

System structure can take many forms including a geometric structure, a chemical structure, or a physiological structure. The use of object-oriented design for analysis of system structure is well known and is one of the first applications of object-oriented programming dating back to the 1960s. The biological and physical systems in agriculture and natural resources are analyzed in this fashion by decomposing a complex system into simpler interconnected parts and subparts. Modular, object-oriented designs are widely used (Beck et al., 2003; Kiker, 2001). Of course, traditional object-oriented design uses programming languages such as Java or C++ as a representation language.

Using an ontology is the next step in this approach (Fishwick and Miller, 2004). There are several advantages to elevating the object comprising the system to the status of ontology objects. For one, the model description and behavior is forced to be done in an entirely declarative fashion (representation based on concepts and relationships). Ontologies do not utilize methods or program code to represent the behavior of model. By using ontology objects, model components can be classified and interrelated based on their meaning. System structure is made explicit in a way that can be exploited by ontology reasoners in order to compare and contrast model structures.

Representing Equations and Symbols in a Model

Model behavior can be described entirely using mathematical equations (Cuske et al., 2005). Equations are composed of symbols, and each of these symbols can be represented as a concept in the ontology. This enables the symbol's meaning to be more exposed and accessible to analysis and manipulation than if the symbols were encoded as a computer program. Whereas equations describe the quantitative behavior of variable, the variables are also symbols, and the things the symbols represent can be made explicit. Furthermore, the basic mathematical operators can also be treated as symbols and described in the same fashion.

Equations can be stored in the ontology by representing them as tree structures. For example the formula:

$$NH4^{+} = Nt - NH3 \qquad \text{(Equation 4-1)}$$

can be expressed using the tree structure in Figure 4-1. The tree is rooted on the equal symbol, and equal has a left side and right side which are the first two branches in the tree. Operators, such as minus, are nodes in the tree with subtrees for each of the operator arguments. Each node in the tree, including operators and variables, become

concepts in the ontology. Each concept includes associations to related concepts, for example “minus” contains associations to the concepts being subtracted.

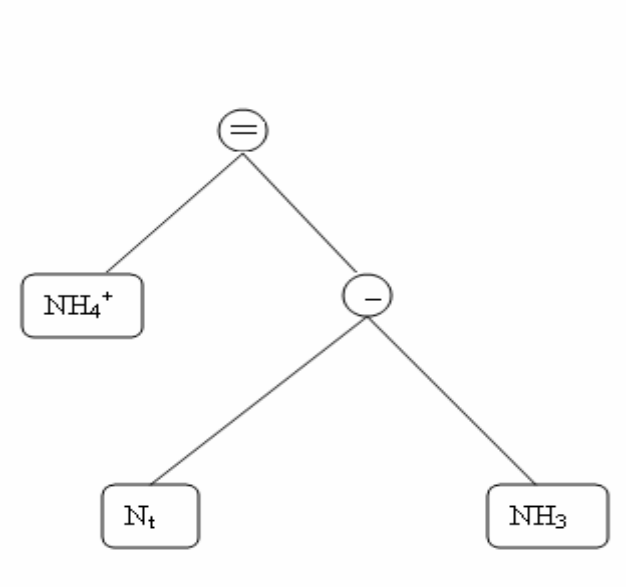

Figure 4-1. Representation of equation 4-1 as a tree structure

The advantage of better defining symbols appearing in equations is improved interoperability of concepts and associated symbols appearing in different models. In addition, with the inclusion of basic operators, the ontology can classify groups of equations and organize them taxonomically from generic forms to specific applications. This will lead to discovery of similarities in forms of equations used in different models, and will help to communicate among different modelers (Altman et al., 1999).

While an ontology is a valuable tool for representing the meaning of the symbols appearing in equations, it has no facilities for solving equations or even performing simple arithmetic operations needed to do simulation. Although it is possible that an ontology language such as OWL could be extended to support analytical equation solving, this area has not been explored and goes beyond the scope of ontology reasoners. Instead, whereas the ontology acts as an excellent library for equations and their symbols,

external facilities are needed to solve the equations. An external code generator can take equation structures that are stored in the ontology and produces XML, or program code in C++ or Java (or other languages) that can implement the simulation.

Reasoning

The power of ontologies lies not only in their ability to provide declarative representations of concepts and their relationships, but also the ability to automatically reason about those concepts. Basic reasoning facilities include ontology validation, automatically determining subsumption relationships (determining if class A is a subclass of class B), and classification (automatically determining the location of a new class within the class taxonomy). Extended facilities included automatic clustering (conceptual clustering) of concepts, and analogical reasoning or similarity-based queries and case-based reasoning. These facilities can be applied to simulation in order to automatically classify models, model components, and the equations and symbols used in the models. Query facilities based on reasoning would help to locate simulation elements within a large collection. Clustering techniques can compare the structure of two models and tell how they are similar or different.

For example, the knowledge in an ontology of solid waste management domain can be used for automatically generating equations based on physio-chemical equilibrium laws. A particular law can be applied based on the specific property of an individual symbol. In the SEBAC simulation , fatty acids dissociate into fatty acid ions based on a physio-chemical equilibrium law, and that law is represented by an equation. The reasoner can automatically instantiate an equation corresponding to the law when it finds that an individual of the fatty acid class has a property called “in equilibrium with” and

the range of the property is fatty acid ion. It would use the particular properties of the individuals involved to parameterize the equation

Generating and Integrating Documentation and Training Resources

If the ontology is part of a complete database management system, the ontology can store and organize any content, including multimedia content in the form of rich text, images, 2D/3D animations, and video. In the context of simulation, this creates a complete environment for all information associated with the simulation. In particular, all research materials (experimental procedures, raw data, statistical analysis, technical reports, journal articles) and educational resources (training-based simulations, scenario training, case studies) can be integrated.

How to Build an Ontology-Based Simulation: Bioprocessing Example

Sequential Batch Anaerobic Composting (SEBAC) is an anaerobic digestion process that decomposes organic matter into methane and carbon dioxide by a series of reactions in the presence of several microorganisms. The details of the SEBAC are explained in the section "Domain Studied" of chapter 2. A mathematical model was developed to understand the SEBAC system and to study the response under various feed conditions (Annop et al., 2003). The model consists of a set of differential equations, which have been constructed based on mass balance and physio-chemical equilibrium relationships. This study did not implement the tools (SimulationEditor and EquationEditor) but used these tools for developing ontology-based simulation for the SEBAC process. The steps in building the SEBAC model based on ontology are as follows:

Collection of Relevant Documents

The first step in building an ontology-based simulation was to collect all relevant documents such as technical papers of the system and any existing related models. In the case of the SEBAC simulation, an existing model had already been implemented using Matrix Laboratory (MATLAB) (Lai, 2001),. Available documents included a graduate thesis describing the variables and equations used in the model (Lai, 2001), a research publication describing the implementation of the mathematical model (Annop, 2003), and source code of the MATLAB implementation.

It would have been useful to have access to a conceptual model for understanding the conceptual schema of the system. A simple conceptual model of the SEBAC process was sketched for understanding the SEBAC domain. Figure 4-2 shows the conceptual model with nine concepts (Owl:Class) and three types of interactions or relationships (Owl:ObjectProperty). These concepts have individuals which can be mapped to the variables used in the simulation. There were six individuals of bacteria and six individuals of fatty acids in the SEBAC system which could be mapped to the state variables of the model.

Define Model in Terms of Elements

The next step was to define the model in term of elements. Elements were used to modularize the model into logical units. Related classes, individuals, properties and equations were entered in a particular element. The description of the model in terms of elements was helpful in understanding the structure of the model. Typically, a modeler designs a particular model by creating a graph containing elements and links indicating the information flow between elements. SimulationEditor (Figure 4-3) was used for building the model structure in the form of an element graph. SimulationEditor also

contained facilities for automatically generating and running simulations and generating reports.

The SEBAC simulation involved a biological process. The simulation was described in terms of elements which captured the important processes like bioconversion of fatty acids and substrate and dissociation of fatty acids. Figure 4-3 shows the elements of the SEBAC simulation and gives an overview of the SEBAC process including various transformations that occur during the process.

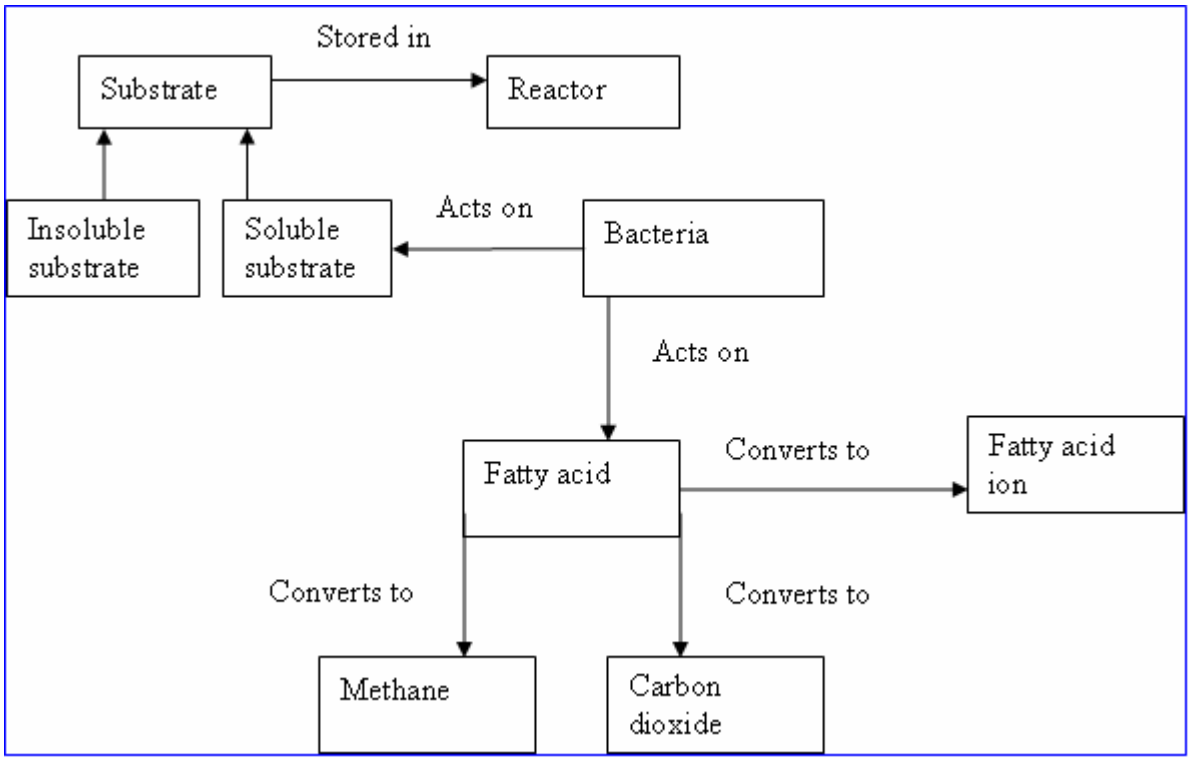

Figure 4-2. Conceptual model of the SEBAC system

Identifying Classes, Individuals and Properties

After defining the general elements of the model, specific concepts in the model were identified. For the SEBAC system, the concepts were identified from the list of variables used in the model (Lai, 2001). From these, the following classes with the

corresponding properties (constants, parameters, yield coefficients and variables) were created:

- Reactor: liquid volume, gas head space, reactor temperature
- Fatty acid ion: equilibrium constant for dissociation, conversion factor
- Fatty acid
- Bacteria: biomass death rate, half velocity constant, maximum growth constant
- Methane
- Carbon dioxide
- Soluble substrate and insoluble substrate

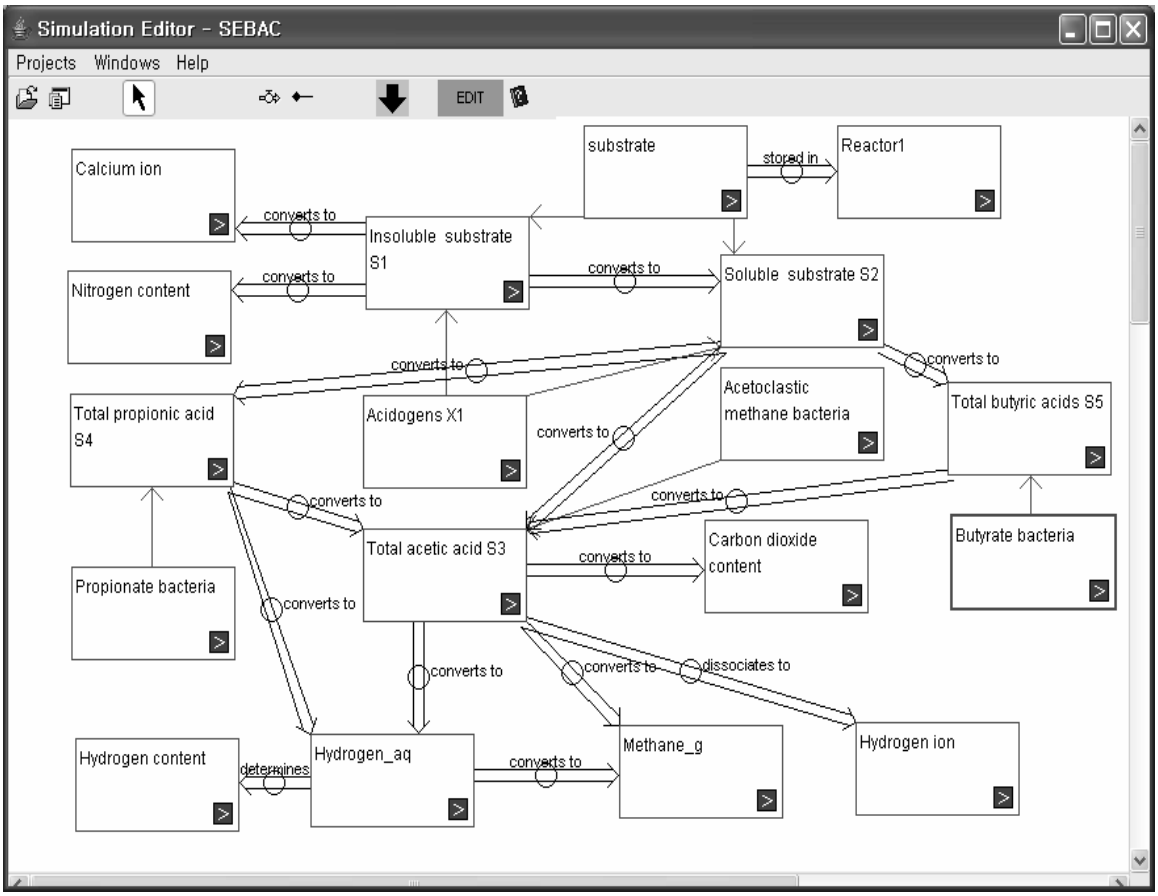

Figure 4-3. SimulationEditor diagram for SEBAC process showing elements of SEBAC simulation and showing various transformations that occur during the process

Some of these classes had several individuals. For example, there were three individuals of fatty acid ion, and each fatty acid ion had a specific value of equilibrium constant for dissociation and conversion factor. Relevant classes, individuals, and

properties were entered in a particular element. Figure 4-4 shows how an individual called "Ammonium ion" was entered into the ontology database. The other classes, individuals and properties were entered into the database in a similar fashion.

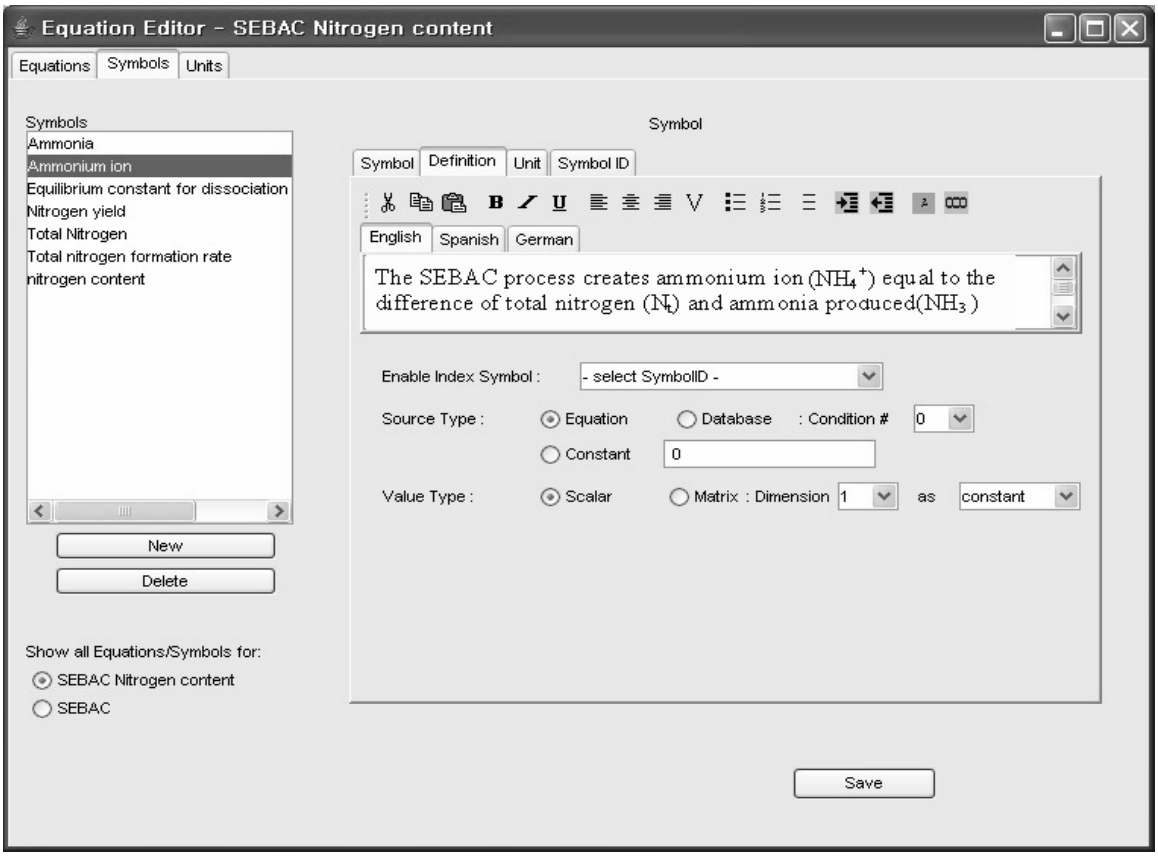

Figure 4-4. Interface of EquationEditor to input the concepts in a particular element of the simulation

In conventional modeling languages, the meaning of the symbols and the relationships between the symbols are not defined explicitly. For example, the SEBAC model had symbols for various forms of nitrogen such as ammonia, nitrate, and ammonium ion, but the simulation written in MATLAB does not explicitly specify the relationship between these forms of nitrogen or the meaning of each form. The meaning

of the symbols and relationships can be defined explicitly using an ontology. Figure 4-5 shows a portion of the ontology for different forms of nitrogen.

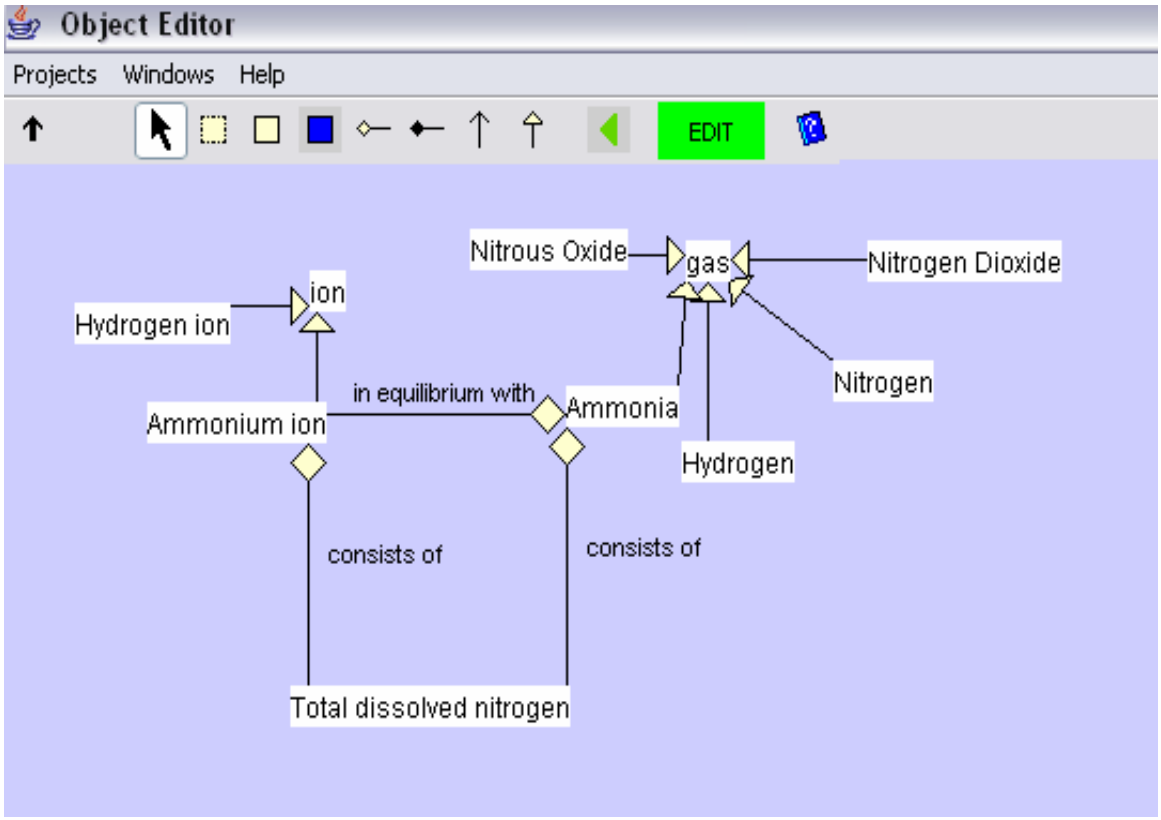

Figure 4-5. Ontology for different forms of nitrogen

In the SEBAC model, total dissolved nitrogen was found in the form of ammonia which in turn could be found in two forms: ammonium ion (NH_4^+) and dissolved ammonia gas (NH_3). In Figure 4-5 there is a relationship called "consists of" with a domain of total dissolved nitrogen and a range of forms of ammonia (NH_4^+, NH_3). Ammonium ion concentration was calculated by the difference of total dissolved nitrogen and ammonia. NH_4^+ and NH_3 were in equilibrium, and their concentration is given by the equation:

$$NH_4^+ \leftrightarrow NH_3 + H^+ \qquad \text{(equation 4-2)}$$

Figure 4-5 displays a property called "in equilibrium with" having NH_4^+ as a domain and NH3 as a range. This property modeled a reversible conversion between the two forms of ammonia (NH_4^+ and NH_3). Ammonia was defined as a specific kind of gas, so it was also a subclass of the class gas.

Define Equations

The equations describing dynamic behavior were entered in the system after entering the classes, individuals, and properties of symbols which were used in the equation. Figure 4-6 shows the interface of EquationEditor for entering an equation that represents the relationship between total dissolved nitrogen, ammonia, and ammonium ion concentration.

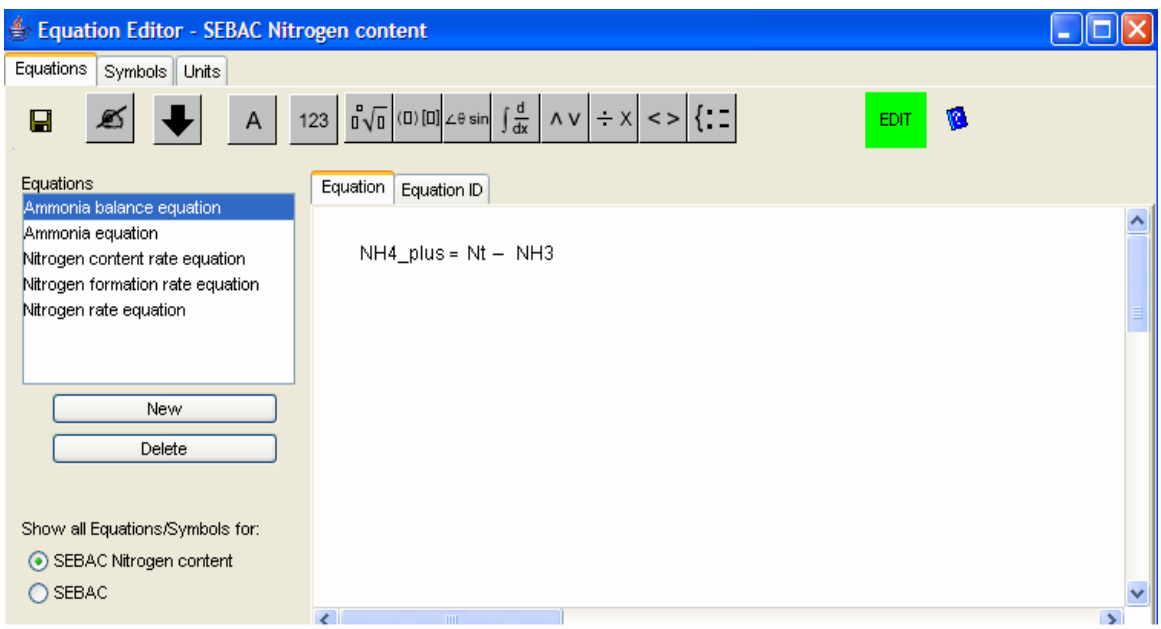

Figure 4-6. Interface of the EquationEditor for entering equation

An equation models the dynamic relationship between concepts (classes) and represents a statement of a specific law. The Michaelis-Menten equation (Heidel and Maloney, 2000) models a relationship between acid and bacteria. In the SEBAC system, Acetic acid is an individual of the acid class and acetolistic methane bacteria is an

individual of the bacteria class. The acetolistic methane bacteria acts on acetic acid, and this relationship can be modeled by Michaelis-Menten equation. These relationships can be explicitly shown in ontology as properties. It is also possible to store the specific laws in the ontology so that the equations can be automatically generated based on the specific relationships between individuals by using an ontology reasoner.

Enter the Initial Values of State Variables

Initial values of state variables were entered manually using an input form which was generated automatically based on the logic that each differential equation has a state variable and that an initial value was required for each state variable. The SEBAC simulation has twenty one state variables, so the input form has twenty one text fields. The value of constants (like the universal gas constant) and other parameters used in the simulation were stored in the ontology as properties of individuals representing these constants.

Generating Program Code for Implementing the Simulation

Program code for running the simulation was automatically generated by processing the descriptions of model structure and behavior (equations) stored in the ontology. Currently, the system generates Java code, but other languages can also be supported. The code generation involved retrieving equations and symbols belonging to each element in the ontology database and making a reference list of symbols having the hierarchical structure of operators in each equation. A Java class was generated for each element of the simulation (mainly to partition the code into logical modules). The symbols for variables belonging to an element were generated as member variables in the Java class while the equations were generated as Java methods. Each method returned a value for a particular variable based on an equation defined for that variable. For

example, a Java method was generated corresponding to the ammonia balance equation, as shown in Figure 4-6, that returns the value of NH_4^+.

Execution of Simulation

After generating the Java code, the code was compiled and the simulation was executed. The simulation results were presented in the form of charts and tables. In order to enhance interpretation, the results of the simulation could also be presented as an animation. The dynamics of the SEBAC simulation were shown in term of reactors that change colors based on pH and other chemical properties of the system (Figure 4-7). The ontology facilitated creating these animated interfaces by storing graphic objects - as described in chapter 3 - that could be used to render an animation along with the associated model concepts.

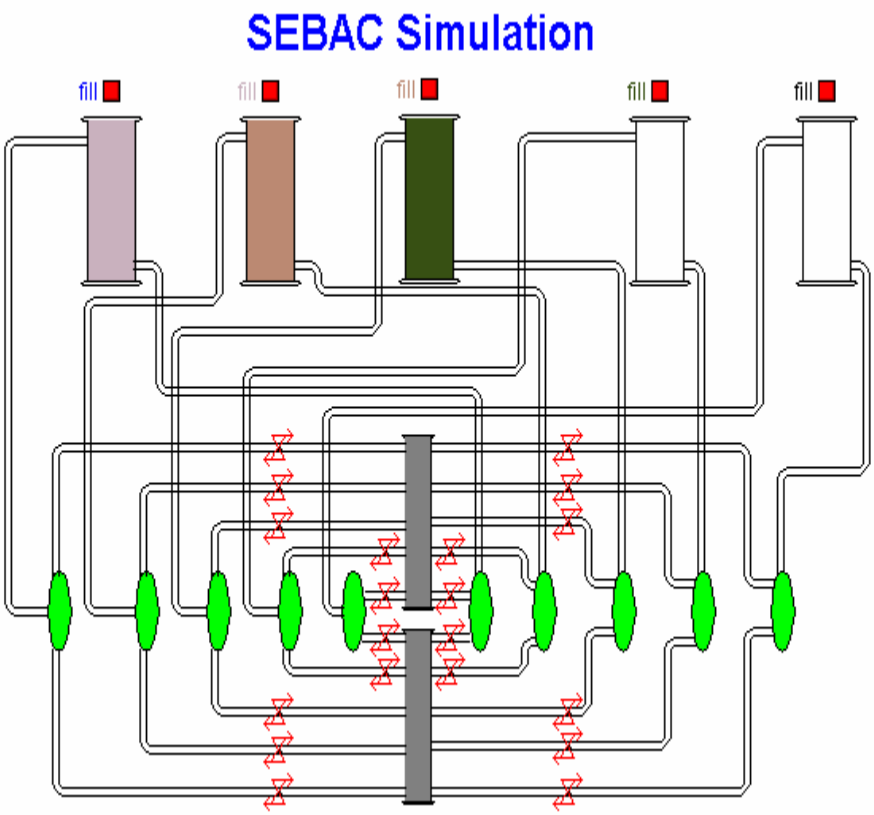

Figure 4-7. Interface for presenting results of SEBAC simulation using animation

Conclusions

This chapter explored several ways in which ontologies can be applied to mathematical modeling. As an example, an ontology based simulation was developed in the bioprocessing domain. The development process involved seven steps including collection of relevant documents; defining the model in terms of elements; identifying classes, individuals, and properties; encoding equations; entering initial values of state, constant, and other parameters; generating code; and executing the simulation.

The development of an ontology for simulation models explicitly exposes knowledge contained in models at a higher level. This knowledge can be further used for constructing conceptual models, simulations of similar systems, and educational and training materials. The construction of an ontology will allow better communication of knowledge about models, model elements, and data sources among different modelers; It will enhance interoperability between different models, increase the reusability and promote sharing of model components.

CHAPTER 5
CONCLUSIONS, CONTRIBUTIONS, AND FUTURE DIRECTIONS

Conclusions

Documenting Research Information

The presented work showed that the content management approach (i.e., using a database to store research information) can be used for documenting research information. The information was first structured as an ontology (structured information) and stored inside an object database (an ontology management system). This approach allowed the documentation of research at a very fine level (i.e., documenting research at the level of concepts used in various research projects) instead of storing the educational materials at only a course level in the form of documents, presentations or other formats that fail to explicitly represent content. There can be an overlap of concepts used in various projects, and the overlap of concepts can be used for identifying similarities in various projects. For example, both SEBAC project and BMP project used the concept of anaerobic digestion, so the overlap of concepts in ontology can infer the similarity in BMP project and SEBAC project.

Methodology for Generating Educational Material by Reusing Information

The structured information was used for creating a variety of educational materials such as websites, animation and reports. A JSP application was developed for creating Web pages from an ontology and a Java animation was developed for explaining the dynamic processes used in the research projects. The concepts used in the dynamic process were stored in the database, and these concepts can also be accessed as a website.

It was shown that the ability to reuse information in a variety of formats has the following advantages:

- Duplication of efforts is minimized: The content management approach decreases the cost and time for producing educational materials.
- Enforcement of information integrity: Using an ontology as a single source of information enforces information integrity within an organization like ES CSTC. The information can be updated and verified at a central location (ontology database) instead of checking the accuracy of information in various formats.
- Separation of presentation and content: The presented approach allows the separation of content from presentation which allows updates or modifications in presentation without changing content and vice versa.

Presenting Dynamic Information of a Lab Exercise as Educational Simulation

Based on the results of the evaluation of simulations, it can be concluded that the simulation can be used to effectively teach a lab exercise. The effectiveness of simulations also depends on the approach of integrating simulations in the instruction, that is, the simulations can be either shown to the students as a demonstration or students can run the simulations on their own machine. The confidence of a student in the lab concepts increases when the student ran the simulation on his/her computer. The use of simulation helps in teaching the lab where it is practically infeasible to teach the lab as a hands-on approach because of the high cost of the equipment and chemicals involved. Simulations can also serve as a replacement experience for universities and colleges that do not have a waste management laboratory. The computer-based simulation can also be used to augment the real laboratory experience.

Representing Knowledge of a Mathematical Model by Ontology

The development of an ontology for mathematical models explicitly exposes knowledge contained in models at a higher level. This knowledge can be further used for constructing conceptual models, simulations of similar systems, and educational and

training materials. The construction of an ontology will allow better communication of knowledge about models, model elements, and data sources among different modelers; enhance interoperability between different models; and increase the reusability and sharing of model components.

Contributions

- This project illustrated a content management approach combining an ontology and database for structuring and storing content. It facilitated the development of simulations and other educational resources. This approach was used for developing educational materials in the domain of waste management technologies at ES CSTC.
- The dynamic information of a project (process, lab exercise) was presented as a simulation. The interactivity of the medium was beneficial in showing the concepts effectively. The simulations were evaluated in classroom settings at the University of Florida.
- A library of Java classes was developed during the generation of simulations. These Java classes can be reused to create similar simulations.
- An ontology for three projects was created for generating educational material in the domain of solid waste and wastewater. The ontology can be used in generating reusable learning material.
- The process of generating an ontology for a simulation or mathematical model revealed a new approach of representing models in terms of concepts and relationships between concepts.

Future Directions

Ontology-Based Instruction Design

This study focused on representing the content of educational material as an ontology. During the development of the website, it was realized that the instructional design could be a next step for representing the concepts of ontology in a learning context. An ontology of instructional design can be integrated with an ontology of research projects for developing courses (Sepúlveda-Bustos et al., 2006). Furthermore,

future work can also be focused on developing a SCORM compliant course using domain ontologies that were created during this project.

Ontology Reasoning

The presented project did not focus on ontology reasoning, which is an important function of ontologies. The ontology reasoners could be used for selecting appropriate teaching method based on the ontology of instructional design and validating instructional material. Future work can also involve application of reasoners in modeling. One of the application of reasoners is generation of equations based on relationships between different concepts in a model.

Development of Tools for Developing Online Lesson

The generic tools used in the presented project were appropriate for developing ontologies but were not specifically designed for producing online lessons. Future work should also be focused on developing custom authoring tools that can more rapidly address instructional design issues because they support features tailored specifically to development of educational materials.

APPENDIX A
EVALUATION FORM OF BMP SIMULATION

Name :
Student #

Section 1. evaluation: Please do the evaluation after reading the lab handouts or performing virtual simulation.

Part a: Technical evaluation (multiple choice)

1. Objective of the experiment?
    1. To estimate biochemical methane potential of a substance and estimate the rate of anaerobic degradation
    2. To measure biochemical methane potential
    3. To determine Aerobic digestibility
    4. To measure Aerobic digestibility

2. How many stock solutions are used?
    1. 6
    2. 7
    3. 8
    4. 5

3. Inoculum is added at --- degree C.
    1. 29
    2. 30
    3. 32
    4. 35

4. What is difference between aspirator bottle and serum bottle?
    1. Aspirator bottle is used for making medium and serum bottle is used for storing stock solution.
    2. Serum bottle is used for making medium and Aspirator bottle is used for storing sample
    3. Aspirator bottle is used for making medium and serum bottle is used for containing the bioassay
    4. Aspirator bottle is used for storing stock solution and serum bottle is used for storing sample

5. Purging is done with which gas?
    1. N2
    2. H2

3. O2
4. N2 – CO2

6. Purging is done for removing which gas?
   1 N2 – CO2
   2. H2
   3. O2
   4. N2

7. What is in the inoculum digester?
   1 Anaerobically digested dog food and mixed cultured bacteria
   2 Aerobically digested dog food, mixed cultured bacteria and water
   3 Aerobically digested dog food, and water
   4 Anaerobically digested dog food, mixed cultured bacteria and water

8. What volume of inoculum is added to the media?
   1. 20% by volume
   2 10 ml
   3 40 % by volume
   4 50 ml

9. What does heated copper column do?
   1 Absorbs CO2 from the gas stream
   2. Absorbs O2 from the gas stream
   3. Absorbs N2 from the gas stream
   4. Absorbs N2-CO2 from the gas stream

10. What are the functions of Na2S and Reazurin
    1. Na2S is redox indicator and Reazurin is a reducing agent
    2. Na2S is reducing agent and Reazurin is a reducing agent
    3. Na2S is reducing agent and Reazurin is a redox indicator
    4. Na2S is redox indicator and Reazurin is a redox indicator

Part b: Subjective evaluation

Please rate each of the following in connection to your experience of BMP lab from 1 to 5 where: 1 is the lowest priority, and 5 is the highest priority.

1 2 3 4 5

1. I am encouraged to learn
2. I am confident with the concepts used in BMP lab.
3. Enabling student to work through course materials at their own pace
4. Developing student's creativity and skills
5. Applying what you are learning to "real world" situations
6. Teaching students to work together

To what extent do you agree or disagree with each of the following statements regarding the BMP lab:
(select only one response per question)
Strongly Agree (SA), Agree (A), Disagree (D),,Strongly Disagree,(SD), Not Applicable(N)

7. The learning experience was interactive
8. I had a good learning experience

APPENDIX B
EVALUATION FORM OF MAPR SIMULATION

Name:
Student I.D.:

Virtual experiment evaluation: Please do the evaluation after reading online lesson and performing simulation (animation)

Part a. Objective Evaluation

Evaluation of Online Lesson

1. The semiconductor used in photocatalysis is…
   1. Barium ferrite
   2. Titanium dioxide
   3. Silica
   4. Activated carbon

   Ans:

2. What is the primary oxidant in photocatalysis?
   1. Hypochlorous acid
   2. Hydrochloric acid
   3. Hydroxyl radical
   4. Hydroxyl ion

   Ans:

3. What are the organic molecules converted to when oxidation is complete?
   1. UV light
   2. Carbon dioxide, water, and mineral acids
   3. A polymer
   4. Sulfur dioxide and nitrous oxide

   Ans:

4. Which type of electron is excited to form an electron/hole pair?
   1. A conduction band electron
   2. A valence band electron
   3. A hot electron
   4. All of the above

   Ans:

5. The purpose of magnetic agitation is to
   1. Activate the catalyst
   2. Begin the breakdown of the contaminant
   3. Maximize photocatalysis
   4. Keep the system stable

Ans:

Evaluation of Simulation

1. The alternating current magnetic field is generated by
   1. Solenoid
   2. UV light
   3. Wastewater
   4. all of the above

Ans:

2. Maximum performance of the MAPR is at what solenoid frequency
   1. 20 Hz
   2. 80 Hz
   3. 120 Hz
   4. Performance is same between 20 and 80 Hz

Ans:

3. Which of the following is *not* used in MAPR experiment
   1. Heater
   2. UV light
   3. Frequency generator
   4. Spectrophotometer

Ans:

4. What is one of the methods used for determining the extent of photocatalysis?
   1. Counting by hand
   2. Spectrophotometer
   3. MAPR
   4. Inductively coupled plasma

Ans:

5. Which of the following is true about MAPR process ?
   1. Only magnetic agitation is required for effectively treating wastewater
   2. There is no effective treatment of wastewater without UV light
   3. There is no effective treatment of wastewater without magnetic agitation
   4. Effective wastewater treatment requires UV light and magnetic agitation

Ans:

Part b: Subjective evaluation

Please rate each of the following in connection to your experience of MAPR lab from 1 to 5 where: 1 is the lowest priority, and 5 is the highest priority.

1 2 3 4 5

1. I am encouraged to learn **…**
2. I am confident with the concepts used in MAPR lab**….**
3. Enabling student to work through course materials at their own pace**….**
4. Developing student's creativity and skills**…..**
5. Applying what you are learning to "real world" situations**…..**
6. Teaching students to work together**….**

To what extent do you agree or disagree with each of the following statements regarding the MAPR lab:
(select only one response per question)
Strongly Agree (SA), Agree (A), Disagree (D),,Strongly Disagree,(SD), Not Applicable(N)

7. The learning experience was interactive**….**
8. I had a good learning experience**…..**

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BIOGRAPHICAL SKETCH

Rohit Badal was born on January 4, 1976, in Dewas, India, to Saroj Badal and R.S. Badal. He was formally educated at St. Mary's Convent School at Dewas, India, and passed the pre-engineering exam at the state level (Madhya Pradesh) for starting Bachelor of Technology program in Chemical and Biological Engineering at Regional Engineering College, Jalandhar (Now known as the National Institute of Technology, Jalandhar). He completed the Bachelor of Technology in 1998 and joined Omen Drugs Corporation as a Trainee Engineer for one year. On August 1999, he entered the graduate program at Louisiana State University. From August 1999 to July 2002, he worked as a Research Assistant at the Department of Biological and Agricultural Engineering, LSU, and completed his master's thesis on "Supercritical Carbon Dioxide Extraction Of Lipids From Raw And Bioconverted Rice Bran" under Dr. Terry Walker. After completing his Master of Science, he started the doctoral program at the University of Florida and was awarded a research assistantship under Dr. Howard Beck in the area of information technology.