THE RIGHT CHEMISTRY: A CONSTRUCTIVIST APPROACH TO LEARNING CHEMISTRY

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ABSTRACT
The Right Chemistry is a project under development for the Internet delivery of Digital Courseware and Learning Objects that cover the objectives of grades 11 and 12 Canadian Chemistry curriculum. It is made up of interactive multimedia, 2D and 3D high-end animation and Discovery Applets. The goal is to offer a complete curriculum in chemistry in the form of a fully interactive, user-friendly, visually appealing and learner-centered courseware that allows students to work at their own pace and level. The product which include student logon and progress-tracking options, offers over 1200 Learning Objects, making up to 15 000 pages of multimedia activities developed in XML and ChemML.

KEYWORDS
Digital courseware, learning objects, discovery applets, learner-centered courseware, chemistry teaching/learning, XML, ChemML

"Multimedia technologies enable the creation of environments in which constructivist learning can take place…In the process, students create new and examine existing knowledge structures through the exploration of a topic as well as an appreciation for it." (Heidmann, Waldman and Moretti, 1996)

INTRODUCTION

Jean Piaget, one of the "fathers" of learning theory research, argued that intelligence develops in all children through the continually shifting balance between the assimilation of new information into existing cognitive structures, and the changing accommodation of those structures themselves to incorporate the new information. Growing acceptance of Howard Gardner's theory of multiple intelligences (Gardner, 1993) should prompt educators to align instructional strategies to accommodate changing and differentiated learning approaches. More recent research about theories of multiple intelligence, metacognition and constructivism are some of the factors influencing our understanding about how learning occurs (Manner, 2001; Rickey & Stacy, 2000).

From a more didactic point of view, a constructivist approach views learning as a process whereby learners, through a learner-centered approach, construct their own meaning (Astolfi & al., 1997). Research studies in instructional science agree on the constructive aspect of learning, that knowledge cannot be transfer from one person to another, nor be done without the active participation of the learners who, all by themselves build up their knowledge and establishes the significant connections (Astolfi, 1989; Glasersfeld, 1994). Constructivism is opposed to the tradition whereby language is a meaning of transferring knowledge and stipulates that no direct access to the teacher's knowledge is possible. Ausubel suggest the organization of « cognitive bridges » by teachers that would facilitate anchoring new knowledge in the cognitive structure of the students. Instructional model should stage the students as the main organizers of their knowledge whose self-learning brings them to epistemological ruptures. The role of didactic is to make those teaching strategies possible (Astolfi, 1989). If constructivism is opposed to a transmission-reception model of learning, it is also opposed to a solely learner-centered pedagogy. The students build and learn in a non-linear way by differentiations, generalizations and ruptures. If that all stand on individualized work, it also has to take place within collective situations where cognitive conflicts can occur an enhance learning (Astolfi et al, 1997).

Combining constructivism and technologies creates a synergy in education, the later permitting a more individualized and supporting environment in a constructivist view of learning. The approach and the tool together result in an education much more attentive to the students' understanding and to the active use of their knowledge and abilities. Concretely, the computer forces a learner-centered approach of teaching and more personalized interventions (Perkins, 1991). Indeed, instructional design which encourages ownership, control and relevance incorporates a constructivist approach and can enhance learning.

PROVIDING SELF-PACED, INDIVIDUALIZED LEARNING

The relationship a learner has with the environment supporting or facilitating learning is the single most important factor influencing learning outcomes (Sivin-Kachala & Bialo, 2000). One of the fourteen observations of the Documentary Review for SchoolNet (1996) is that "*the new technologies foster a positive, close association of students with the assessment of their own learning, and uses and manages much more demanding assessment methods.*" Whether for knowing or doing, learning is a process of extending the capability to be relevantly present to what is being experienced. Technology-assisted learning provides the avenue for insightful instructional, creative and technical designers to re-craft each individual relationship to information that better correspond to natural and intuitive ways of learning. In a well-crafted technology-assisted learning program, the new relationship to information is based on responding to the immediate dynamics of the individual learner. This is a major distinction from the traditional "class of learners" approach.

Engagement is another important dimension of motivation to learn (Tardif, 1997). Acquiring complex knowledge requires considerable energy, effort and persistence on the learner's part and that is especially true in chemistry, a complex discipline. Indeed, chemistry is known to be very difficult and many studies have reported student's comprehension problems of chemical principles or their inability to make symbolic representations (Kozma & Russel, 1997). Chemistry is complicated mainly because it implies abstract knowledge (Abraham & al., 1992), is very much symbolic and representative (Kozma & Russel, 1997) and because chemical concepts can be and are taught at three levels: sensory (macroscopic), atomic/molecular (microscopic) and symbolic (formulas and algorithms) (Gabel & al., 1992).

Chemistry teaching/learning can certainly use multimedia products that are learner-centered, allowing students to work at their own comfort level, that foster ownership of activities, place high value on the nature of the subject matter, provide visual representations of abstract concepts, encourage challenging interactions, and that include regular, consistent feedback mechanisms and, by doing so, ultimately offer the most potential for sustained cognitive engagement. The product that we are currently developing is designed to respond to all those expectations.

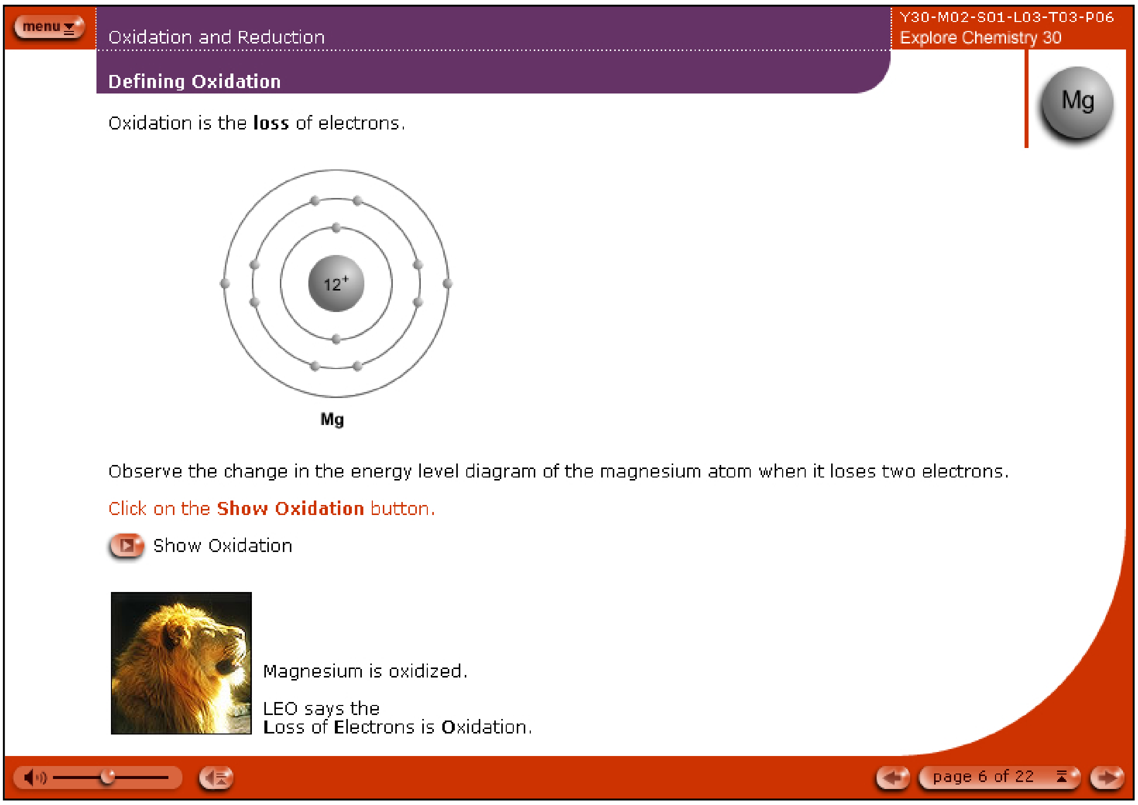

Figure 1. An activity in redox

Careful attention is being taken in the design of the instructional architecture, interface and lesson presentations to ensure that students of all learning styles, all levels of ability, cultural and regional diversities would be equally enfranchised in the learning experience. Special attention is being taken to ensure full integration of cognitive and affective domain processes. Also, particular attention is being given to the need for motivational understanding - impacting attitudes and beliefs of the affective domain.

The product is also being designed for full integration of the right hemisphere with its predominance of image and visualization capabilities and associate, intuitive processing skills and the left hemisphere with its predominance of language faculties and linear, sequential reasoning skills. Full frame graphical environments present the users with contextual, real-world problems. Throughout the courseware, the learners interact with learning objects, 2D and 3D animations, plot points on charts, drag and drop items into measurement instruments, and use simulation tools and discovery applets, like the Atom Builder or the Equilibrium Simulator to solve problems.

SUPPORTING SKILLS DEVELOPMENT

Activities proposed in the product include free or structured exploration of the content; generation of data with the help of simulators; analysis and presentation of data in various forms; and testing of hypotheses concerning the relationships between the properties of the chemical objects being studied. The pedagogical model in the product involves discovery, as the programs allow dynamic access to and manipulation of the most important forms of information in the domain. The learning process consists essentially in the constructive transformation of the student's intuitive models of reality. The learning activities are based on essential concepts, and fully exploit the resources of the environment. They are student-centered, their goal being to develop the competence of the students and both their autonomy and their ability to collaborate.

Students are expected to develop an ability to use thinking processes associated with the practice of science for understanding and exploring natural phenomena, solving problems and making decisions. Students are also expected to do teamwork, respect the views of others, make reasonable compromises, contribute ideas and effort, and lead when appropriate to achieve the best results. These processes involve many skills that are to be developed within the context of the use of the product. Students are also expected to be aware of the various technologies, including information technology, computer software and interfaces that can be used for collecting, organizing, analyzing and communicating data and information.

The skills framework presented here assumes that thinking processes often begin with an unresolved problem or issue, or an unanswered question. The problem, issue or question is usually defined and hypothesis formulated before information gathering can begin. At certain points in the process, the information needs to be organized and analyzed. Additional ideas may be generated—for example, by prediction or inference—and these new ideas, when incorporated into previous learning, can create a new knowledge structure. Eventually, an outcome, such as a solution, an answer or a decision is reached. Finally, criteria are established to judge ideas and information in order to assess both the problem-solving process and its outcomes.

The following skills are not intended to be developed sequentially or separately. Effective thinking is nonlinear and recursive (Bransford, Brown & Cocking, 1999). Students should be able to access skills and strategies flexibly; select and use skills, processes or technologies that are appropriate to the tasks; and monitor, modify or replace them with more effective strategies.

Initiating and Planning
- identify and clearly state the problem or issue to be investigated
- differentiate between relevant and irrelevant data or information
- assemble and record background information
- identify all variables and controls
- identify materials and apparatus required
- formulate questions, hypotheses and/or predictions to guide research
- design and/or describe a plan for research, or to solve a problem
- prepare required observation charts or diagrams, and carry out preliminary calculations

Collecting and Recording
- carry out the procedure and modify, if necessary
- organize and correctly use apparatus and materials to collect reliable data
- observe, gather and record data or information accurately according to safety regulations

Organizing and Communicating
- organize and present data (themes, groups, tables, graphs, flow charts and Venn diagrams) in a concise and effective form
- communicate data effectively, using mathematical and statistical calculations, where necessary
- express measured and calculated quantities to the appropriate number of significant digits, using SI notation for all quantities
- communicate findings of investigations in a clearly written report

Analyzing
- analyze data or information for trends, patterns, relationships, reliability and accuracy
- identify and discuss sources of error and their affect on results
- identify assumptions, attributes, biases, claims or reasons
- identify main ideas

Connecting, Synthesizing and Integrating
- predict from data or information, and determine whether or not these data verify or falsify the hypothesis and/or prediction
- formulate further, testable hypotheses supported by the knowledge and understanding generated
- identify further problems or issues to be investigated
- identify alternative courses of action, experimental designs, and solutions to problems for consideration
- propose and explain interpretations or conclusions
- develop theoretical explanations
- relate the data or information to laws, principles, models or theories identified in background information
- propose solutions to a problem being investigated
- summarize and communicate findings
- decide on a course of action

Evaluating the Process or Outcomes
- establish criteria to judge data or information
- consider consequences and biases, assumptions and perspectives
- identify limitations of the data or information, and interpretations or conclusions, as a result of the experimental/ research/ project/ design process or method used
- evaluate and suggest alternatives and consider improvements to the experimental technique and design, the decision-making or the problem-solving process
- evaluate and assess ideas, information and alternatives

DEPLOYING TEACHING/LEARNING STRATEGIES

The learning objectives have inspired the use of the following teaching/learning strategies:

Strategy 1: Solving a Problem
: Students are given a specific goal. They are somewhat aware of their own abilities, but letting them discover solutions on their own reinforces this awareness.

Strategy 2: Accomplishing a Task
: Students are given a clearly-defined task. They possess the requisite abilities, but must select and sequence them in order to accomplish the task efficiently.

Strategy 3: Forming a Concept
: Students are given considerable latitude to explore new structures and their interconnections. The resulting “cognitive conflict” can lead to the emergence of a concept or a new mental structure.

Strategy 4: Discovering Phenomena
: Students are given the freedom to explore information from the world of chemistry in order to glean whatever catches their interest.

Strategy 5: Integrating Interdisciplinary Goals and Contents
: Students are given the opportunity to discover that the various academic disciplines are not as compartmentalized as the educational system would lead them to believe.

Strategy 6: Communicating Ideas
: Students are given the opportunity and the tools to write a report, make a multimedia presentation, organize a debate and prepare a scientific conference.

ELEVATING ADAPTIVE LEARNING TO A NEW LEVEL

The content of each courseware is structured around a certain number of lessons. Each lesson is organized around components accessible to the learner in any order from a lesson Navigator with linked glossaries, a multimedia communication tool, and several simulation tools and discovery applets. Learning outcomes and prerequisites are outlined on the opening lesson screen.

The following diagram provides a visual for the instructional design of the courseware.

Chemistry 30
- **Module 2** - Electrochemistry
  - **Section 2.1** – Terminology of Redox Reactions
    - Overview
    - **Concept Lesson 2.1.1** – What is a Redox Reaction?
      - Introduction
      - Several **Learning Objects** …..
      - Closure
    - **Concept Lesson 2.1.2** – Redox Definitions
      - Introduction
      - Several **Learning Objects** …..
      - Closure
    - Summary
    - Amalgamation
    - Practice
    - Self Check

Figure 2. Example of the Chemistry Instructional design

Information is delivered based on a student's learning and response profile so that each concept being taught can be confirmed by the student's personal knowledge base or lack thereof. This methodology ensures that information related to the understanding of a concept is present ad infinitum depending on the depth of knowledge the student requires to understand or simply wishes to discover. Once the content is understood the methodology continues to test the student, concept by concept, confirming the complete understanding of content before proceeding.

The content of the Chemistry courseware has been organized into the following hierarchy:

Level 1: High school chemistry courseware
The courseware is the name that is used for each grade level of the chemistry courseware. Seven (7) complete coursewares are being produced.

Level 2: Modules (units or parts of units)
Each of the Chemistry courseware is broken down into several **Modules**. A module addresses a group of related learning outcomes. For example, in Alberta's Chemistry 30 courseware, module 2 is *Electrochemistry*.

Level 3: Sections (natural teaching breaks)
Each module is then further sub-divided into smaller units called **Sections**. Sections are natural breaks for content within a module. Each of these sections is packaged based on how chemistry concepts "naturally group", how the group of related concepts lend themselves to a method of teaching and the applicability of a STS context. Other minor considerations for grouping concepts into a section are the amount of content and teacher preference. Each section is couched in an appropriate theme/context/societal connection. For example, the Electrochemistry module of Alberta's Chemistry 30 is broken down into six sections, the first of which is, *Terminology of Redox Reactions.* Each

Section begins with an **Overview** and includes a **Summary**, an **Amalgamation**, **Practice** and **Self-check**.

The **Overview** sets the context for the Section. Depending upon the topic and type of lesson, the Overview could include movies, slideshow, and pictures of the chemistry been taught in real life situations. The Overview usually includes an interesting question or discrepant event that relates to the topics to be covered within the section. It introduces an interactive multimedia problem that draws on prior knowledge set in the context of a real-world experience. It is an "attention grabber" highly visual and interactive. Overviews are generally 5 to 10 pages in length

The **Summary** brings together the main concepts within the section in the context of the real life situations presented in the overview. The "question" from the Overview is answered or the "discrepant event" explained. Summaries are generally 3 to 5 pages long.

Amalgamation. This component brings together the concepts that were developed in each of the concept lessons. It is a high quality learning object designed to ensure that the parts of the concept lesson are amalgamated into a "whole". The amalgamation may be one or two complex examples designed to show the learner that several concepts may be required to answer or investigate a chemistry problem.

Practice. This component consists of guided practice questions which encompass the entire Section. The Practice component provides an opportunity to apply the knowledge and concepts learned in the Section. Each question may have a HELP button as needed to guide the students to correct answers when they are having trouble. The HELP may correspond to one level of feedback, or it may show part of a sample solution. At the end of each question students will be given an opportunity to try the question again, and see a sample solution. Applying newly learned skills to personal and familiar situations dramatically increases relevancy and retention thus students continue to learn and improve through "learning by doing".

Self-Check. This component gives student an opportunity to evaluate their progress with the concepts that were covered in the section. This component presents a sequence of problems, randomly accessed from a database of problems not utilized by the student in the Practice component. The database is programmed to serve up a pre-determined number of problems based on type of problems and level of difficulty. At the end, the students get their score. They then are able to review the problems, try incorrect ones again and check answers and/or see a sample solution.

Level 4: Concept Lessons (first level concepts)
Concept Lessons are related learning objects grouped together to "cover off" one or two chemistry concepts (curriculum outcomes). Each lesson begins with an **Introduction**, followed by a series of **learning objects (**along with necessary instruction to blend the learning objects together), and ends with a **Closure**. Each lesson is designed to have some sort of engaging introduction like an STS connection, a discrepant event to explain, or a scientific problem to solve.

There are two types of lessons, **Structured Lessons** and **Discovery Lessons**. In Structured Lessons there is a preferred sequence to the order in which learning objects are accessed, while in Discovery Lessons, students visit learning objects in an order of their choosing. In both types of lessons the student is free to choose at any time – not locked in. The non-linear nature of the lesson makes it possible for a topic to be examined from multiple perspectives that promote retention and transfer. Students are required to provide input several times per frame and make branching decisions to use alternate strategies to solve problems as the lesson progresses.

The **Introduction** sets the context for the concept lesson. Depending upon the topic of lesson, the Introduction could include movies, slideshow, and pictures of the chemistry been taught in real life situations. The Introduction usually includes an interesting question or discrepant event that relates to the topics to be covered within the concept lesson. An Introduction to a Concept Lesson is less elaborate than an Overview to a Section. Introductions are generally 3 to 5 pages in length.

The **Closure** ties the concepts within the lesson to the context of the real life situations presented in the Introduction. The "question" from the Introduction is answered or the "discrepant event" explained. Closures are generally 3 to 5 pages.

Level 5: Learning objects (topics – activities, animations, simulations, videos …)
Learning objects include activities, animations, simulations, videos and guided practice. Learning objects have associated with them metadata that includes objectives, prerequisites, learning outcomes and summary. Learning objects are a new way of thinking about learning content. Traditionally, content comes in a several hour chunk; learning objects are much smaller units of learning; typically ranging from 2 minutes to 15 minutes. Learning objects are self-contained, that is, each learning object can be looked at independently. They are also reusable - a single learning object may be used in multiple contexts for multiple purposes. They can be aggregated or grouped into larger collections of content, including traditional course structures. Finally, learning objects are tagged with metadata, that is, every one has descriptive information allowing it to be easily found by a search engine.

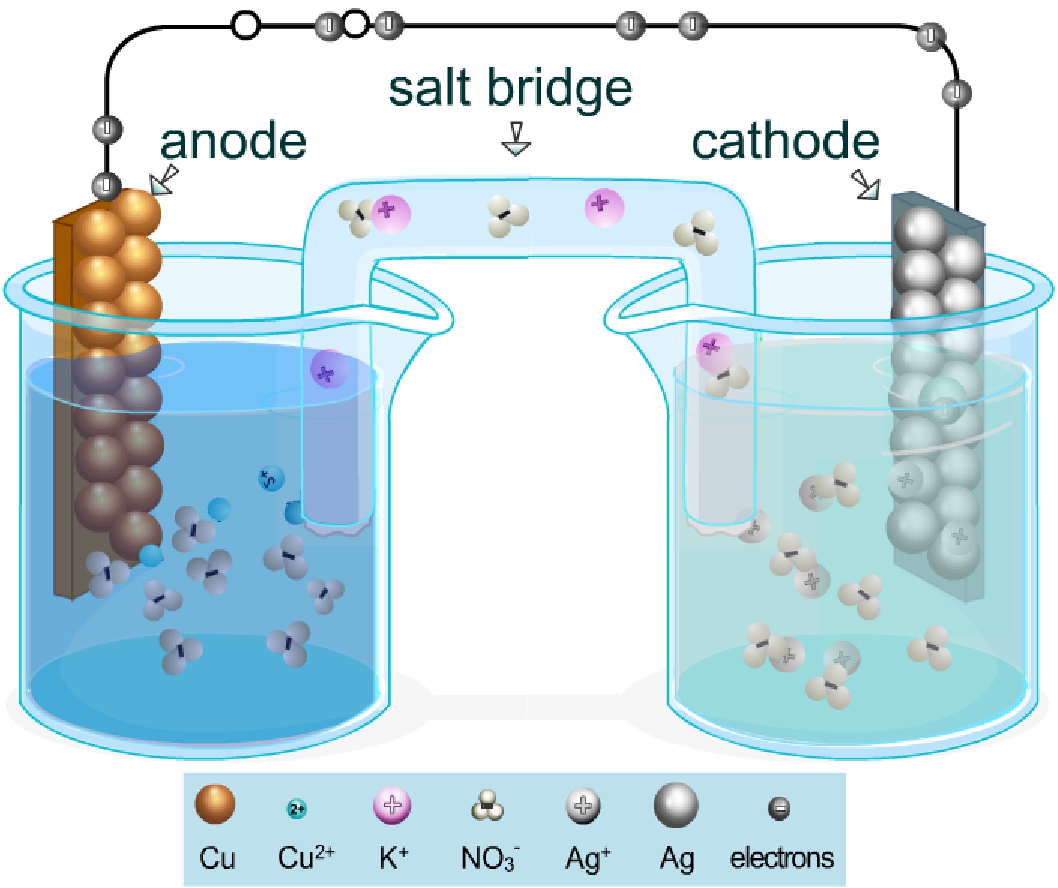

Figure 3. Example of a high-end interactive animation/simulation learning object

Characteristics that make a learning object meaningful are:
- Interactive and engaging
- User friendly and visually appealing
- Clear instructional goal communicated to learner
- Contains challenging interactions, with regular, consistent feedback mechanisms
- Flexible to accommodate all types of learners

- Learner-centered
- Sustained cognitive involvement
- Multiple perspectives that promote knowledge retention and transfer

Learning Objects are divided into a series of **pages** (Level 6). Most pages (frames) consist of a screen of dynamic information and activity. The opening page of the learning object provides a description of the **Objective** of the learning object, and the **Prerequisite** skills. The learning objects demonstrate the concept in all the forms that students might meet in the practice, and at different levels of ability.

The learning object's **Objective** is a brief statement, which describes what the students will learn in the learning object. The **Prerequisite** list prerequisite skills, lessons and/or topics, which are important for students to have achieved, in order to be successful in the current learning object.

The courseware also makes use of interactive learning tools (simulation tools, discovery applets, communication tool and glossary) and generic software functionality (printing, saving, sound output, searching and student monitoring). A set of **simulation tools** and **discovery applets** encourage students to explore, conjecture, reflect on their actions, and formulate their understanding of chemical concepts, skills and procedures. Examples include simulations of concrete materials on screen, such as chemical reactor, equilibrium simulator, and manipulation of symbols or equations to analyze chemical relationships.

A **multimedia communication tool** is included in the courseware. This tool enables students to make exciting interactive multimedia presentations with text, images, animation, video and interactive means of navigation as part of their homework or for communicating findings to the teacher or to other students. The teacher may also use this tool to create interactive multimedia worksheets and/or assessments.

There are two built-in **glossaries** (term and chemical) that students can access at all times. New chemical terms and vocabulary are highlighted to remind students to use the glossaries to access a complete definition and examples.

The product has built-in **tracking and reporting** features. As students successfully complete lesson quizzes, a check mark appears beside completed lessons. Session and results are automatically saved in the student file. Teachers have access to the results-tracker, which monitors each student's progress through each lesson component. Teachers are able to intervene with individual students when, and as-needed. Each page of the courseware as well as the student file can be printed.

The product uses numerous **response models** that provide true interaction between the user and the software. The response models evaluate user input and provide a visible graphical outcome or response to the learner. For example, students may solve a problem by using a pH-Meter. As students input numeric values for concentration or volume in the answer box above the pH-Meter, the graphical printer "prints" out the corresponding titration curves back in the problem for further activities.

FURTHER STEPS

Because effective learning materials should strive to be intrinsically motivating, fostering intrinsic motivation should be the aim of multimedia developers. Extrinsic motivation offers rewards for good responses, whereas intrinsic motivation taps in the excitement of learning and builds on the learner's willingness and desire to learn. In multimedia, sound and graphics used primarily to amuse and entertain very quickly become ineffective extrinsic motivators. Motivation is enhanced when learners have opportunities for choice and control in how and what they will learn and when the reasons for learning are rooted in the learning situation itself (Grégoire, Bracewell & Laferrière, 1996).

The Right Chemistry will require learners to assume an active, engaged role - to select lesson components, to interact with each main "page" of the program, to make decisions about branching within screens and lesson components, to use new knowledge and skills in selecting meaningful tasks in the Practice and Self-Check components.

With this in mind, we intend to do an extensive pilot testing of the materials under development during the 2003-2004 school year. The purpose of the classroom pilot study is to measure it's effectiveness in improving student learning and retention in chemistry. Based on instruments vetted by Ministry of Education officials, student and teacher questionnaires will be developed in consultation with university researchers. We will be collecting data on the following areas:

- Time on Task
- Student Motivation
- Teacher Attitudes
- Change in the Role of the Teacher
- Change in the Role of the Student
- Implementation Issues
- Student Collaboration
- Self-paced Learning
- Student Interaction
- Assessment of Progress and Learning

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