Interactive Multimedia for Adaptive Online Education†

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1. Introduction

Interactive multimedia content has the capability to improve learning performance by enhancing user satisfaction and engagement. Multimedia content also provides better concept representation, which is not possible in conventional multiple-choice and fill-in-the-blank formats. In this article, we present a broader view of multimedia education especially for the years to come. Our vision is to provide publicly accessible education *anywhere, at anytime and to anyone*. We propose an innovative CROME (Computer Reinforced Online Multimedia Education) framework integrating the main components of education including learning, teaching and testing, as well as adaptive testing and student modeling. Our research is conducted in collaboration with industry and is in response to the industrial need and public support for "Online Multimedia Education." By presenting our research and development achieved in the last two years, we hope to share our experience with other researchers and bring awareness to the much-needed outcomes that have not received adequate attention. Our current implementation provides the groundwork upon which more robust, effective and far-reaching multimedia architecture can be developed.

The unique contributions of our system are:

- ❑ Automatic difficulty level estimation for selected subjects, compared to estimates based on user group calibration [1];
- ❑ Adaptive testing using innovative item formats versus using traditional multiple choice items (Moodle's multiple choice, GMAT).
- ❑ Computer-assisted automatic question item authoring, rather than manually creating different questions [2];
- ❑ Custom-designed modules for tracking precise concepts that are lacking in recommendation systems [3]; and,
- ❑ Ability for testing beyond only subject knowledge, unlike other e-learning systems [4, 5, 6].

2. The Mechanism of Education

Historically, education was a commodity affordable only by the rich. This would still be the case for high school studies should free tuition not be offered by some governments. However, inequality of opportunities continues because the rich can afford private schools and tutors. The rich can access additional guidance outside classrooms while the poor have to rely on public school resources. To hire a qualified private tutor in North America, the regular hourly rate on curriculum specific subjects currently range from $40 to $60. In some municipalities, the difference in expenses between attending a private school and a public school can be thousands of dollars per month. The demand for affordable private tutors has created a recent trend in online tutoring, which allows students to reserve specific time slots in advance and, with selected tutors, get help with solving curriculum related questions. The students pay a set monthly fee for a certain number of tutoring hours. Since the service is provided online, the tutors can be remotely located. For example, some service providers take advantage of the lower operating cost overseas and hire tutors in countries like India to answer questions posted online by students in North America. In this kind of out-sourcing service, the issues to address include time difference, curriculum diversity, and the possible language and cultural barriers. Moreover, this approach requires little to no multimedia content because the focus is on the conversation between the tutor and the student either in a cyber chat room or through emails.

A more widely adopted and effective approach to promote global education is through the use of digital multimedia and e-learning. The format of e-learning can be as general as an open access web site like that supported by BBC [4] and Discovery Education [5], or curriculum specific programs provided by universities and

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institutions for high stakes exams, diplomas, undergrad and graduate exams. One example is the distance education programs provided by the University of Phoenix, La Salle and Athabasca University (AU) [6]. The European Union (EU) supported educational research program "new perspective for learning" [7] has helped develop and integrate many components for e-learning and develop learning societies under frameworks FP4 and FP5.

Instead of making educational material accessible online, tutorial DVDs containing multimedia content are also available in computer stores and other outlets. Multimedia education [8] proves to be more effective than the traditional printed material because the dynamic and interactive settings can inspire students to learn and remain interested. Furthermore, abstract concepts are expressed better using acoustic or visual effects, animation and graphics, including 3D navigation. Human computer interaction provides instantaneous feedback to students and helps them feel engaged, like in a game-like environment. Since high speed computers and networks are commonplace in modern societies, online delivery has become an efficient tool to overcome geographic diversity. The use of a common language in cyberspace can narrow the gap in language and cultural barriers. For this reason, our research and development focus is on delivering Online Multimedia Education to promote education anywhere, at anytime, and to anyone.

3. Pervasive Multimedia Education

Online applications have been gaining broad acceptance among the general public, especially after the launch of semantic web and social web such as Second Life, YouTube and Facebook. Companies like Amazon, Google, Yahoo! offer very innovative and competitive online services largely because of user demands. The increasing acceptance of online applications and products by all ages is creating a unique opportunity to make a global impact with online education. There is an abundance of literature in the educational multimedia area covering a variety of topics from games to learner modeling. For example, computer games, played by an individual or collaboratively, have been widely used to teach concepts [9, 10, 11]; visual effects are used to assist learner understanding [12, 13]; artificial intelligence techniques have been used to recommend research papers to learners [14]; active learner modeling [15] has been used to derive information on a peer group learning together, possibly in a collaborative environment; tele-mentoring is carried out through collaborative agents [16]; student performance is explored on a multimedia exam program [17]; and open exams have been set up for MBA/Business school admission [18]. However, most of the literature addresses learning applications of multimedia. The use of multimedia in testing has been relatively limited, compared to learning and training. For those systems supporting testing, most of the test questions still adhere to traditional styles, *e.g.* True-false, Multiple-choice and Fill-in-the-blank, and are not as novel as those proposed in our framework. In addition, our design integrates different aspects of education and is not restricted to a single target component.

4. CROME Framework: Examples of Pervasive Multimedia Learning and Testing Items

In order to illustrate the pervasive power of using multimedia content online and its impact on improving the quality of education, we will show some examples from our CROME implementation. We refer to a curriculum specific question as an "item" following the terminology adopted in Educational Psychology and Measurement. In the following, each example item can be used either in learning or testing depending on the log-on status: a *practice* or *testing* session respectively. Tutorials, hints and correct answers are available to the students in a practice session.

3D Items

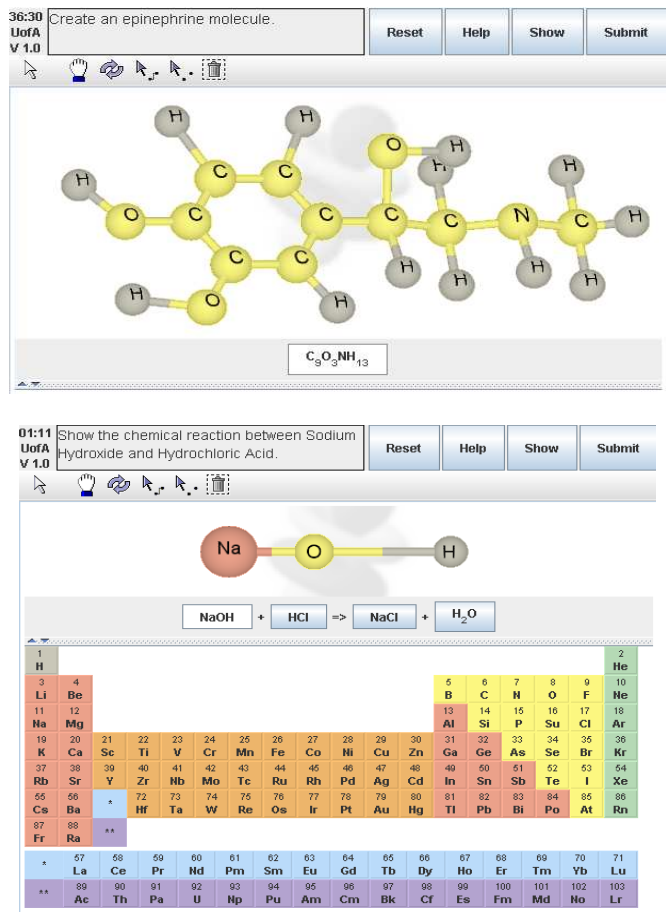


Figure 1: (Top) An item showing a 3D molecule used to test atomic and molecular structure in chemistry; (Bottom) an item that requires a description of the molecular structural changes in a chemical reaction.

In early development, "multimedia" referred mainly to digital images and videos. 3D objects and scenes became an important component only later. One application of 3D content is in chemistry, which can be categorized into three levels: macroscopic level, symbolic level, and atomic level [19]. A chemical phenomenon at the macroscopic level is normally observed in a laboratory and can be shown in videos for learning in addition to the scheduled lab session. The other two levels can be exposed in a more active and interesting manner, instead of writing a formula, *e.g.*,

$$NaOH + HCl \rightarrow NaCl + H_2O\,, \quad (1)$$

or drawing a molecule on paper. The understanding of molecular structures and the change of structures during a chemical reaction, such as breaking bonds inside a molecule, is best presented in a 3D context. Figure 1 shows screen shots of two Chemistry items. Students can use the mouse buttons to pick the required atoms from the periodic table, and drag them onto the canvas. They can then create the appropriate bonds between atoms, as well as navigate (translate, rotate, and zoom) through the atoms and molecules in 3D space. Atomic and molecular symbols in Formula (1) are replaced by 3D objects. A similar idea can be used to create Biology items as well. 3D objects have long been used in the entertainment industry and research, but their use in educational applications is still limited. We believe that it will not be long before tele-surgery and virtual reality tools become more accessible in education, allowing students to practice dissecting a virtual frog instead of using a real animal, and understanding the human body better by manipulating the different organs in virtual space.

Drag and Drop Items (2D and 3D)

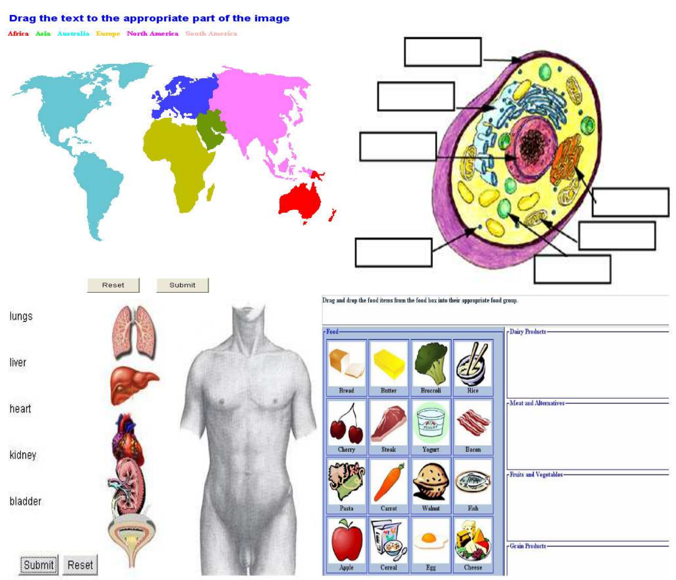


Figure 2: Four example items using drag and drop: (top, left) the student has to drag the correct description to the right location on the map; (top, right) drag the right labels into the answer boxes, (bottom, left) drag organs to positions on the body, and (bottom, right) drag grocery products into correct categories.

A commonly used interaction design is "drag and drop," which allows students to drag text or graphics to the appropriate locations on the screen. An example of a geography item requiring students to drag the correct labels onto the map is shown in Figure 2 (top, left). Drag and drop items can be used in other subjects as well. Figure 2 shows three more examples.

Logical-Mathematical Items

An interactive environment provides more entertainment, and thus motivation, to students when using and analyzing numbers. In the Math item shown in Figure 3 (top), a student needs to distribute the numbered objects into multiple baskets so that the sum in each basket is the same. Another Math item (Figure 3, bottom) requires the student to rotate the dividing lines on the pie chart so that the sizes of the colored portions correspond to the given ratios.

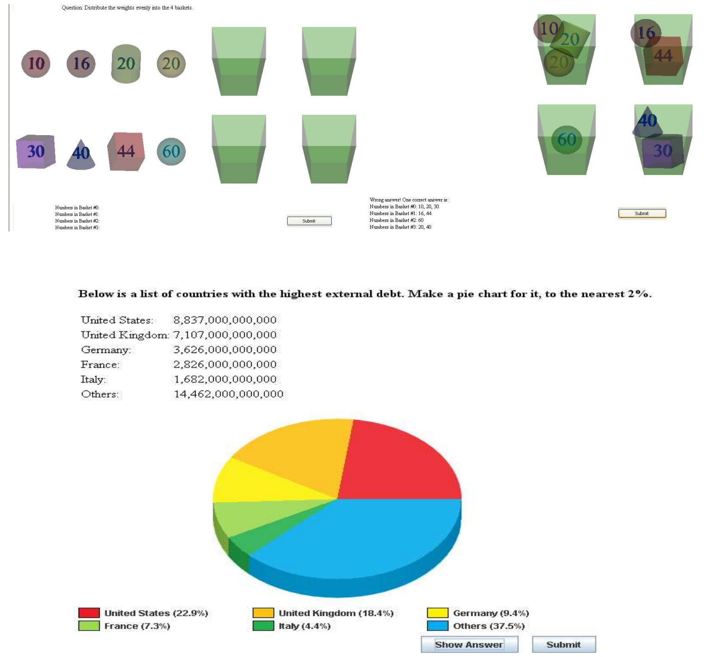


Figure 3: (Top) A Math item requiring a student to distribute numbers into four baskets so that the sum in each basket is the same. (Bottom): A Math item requiring a student to divide the pie chart into correct portions.

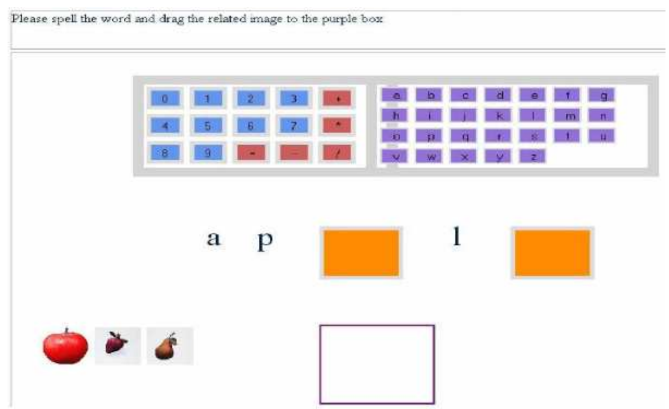


Figure 4: An item requiring a student to spell a word and drag the corresponding image into the answer box.

Language Items

Acoustic and visual effects can be combined to help students relate semantics to spellings and pronunciations. For example, consider different ways of presenting an item to learn and test vocabulary and spelling: Figure 4 shows one example. Note that a student can use the alpha-numeric virtual keyboard displayed on the screen, or use the computer keyboard. Three components are associated with this item: pronunciation (which can be obtained by pressing a button), spelling, and object recognition.

Educational Games

Online games have become commonplace not only among teens but also among adults. Our goal is to present education items in a way similar to what is attracting them to games, so that students can still enjoy their satisfaction through playing games, as well as benefit from learning.

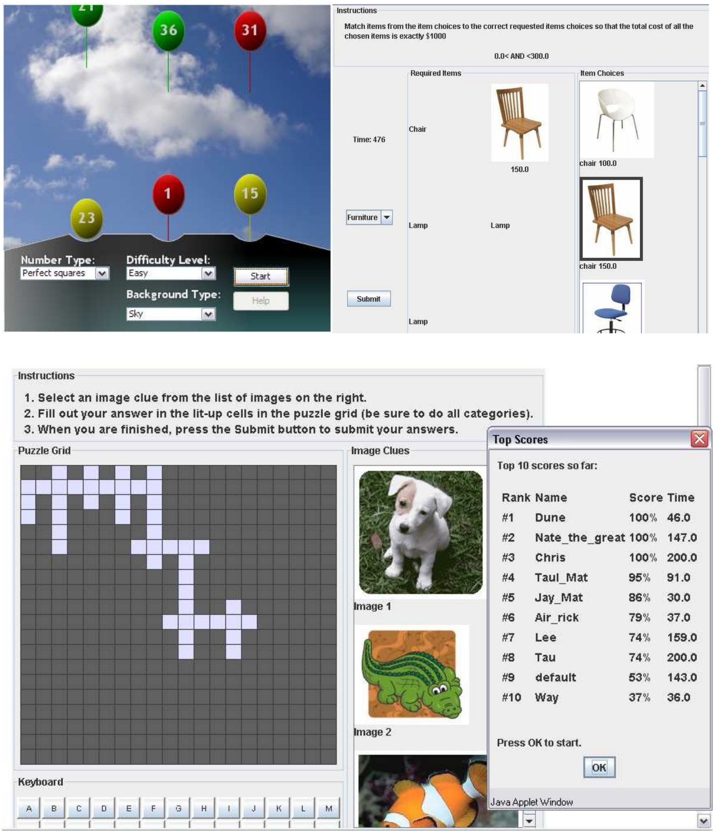


Figure 5: (Top, left): A Balloon Shooting game to practice and test a student's Math skills; (Top, right): A Budgeting game to test Math skills; (Bottom) A Crossword Puzzle to test the vocabulary of a language and the understanding of a word. The top scores are displayed before the game starts to challenge participants.

Education items can be used standalone or in a batch like activities grouped together in a game. A final score is awarded at the end of the game or when there is a time-out. The game also keeps the top scores to challenge participants. The balloon shooting game (Figure 5, top left) tests students' Math skills such as perfect squares, multiples, and prime numbers. A student has to shoot the balloon, provided with sound effect, marked with the target number. The difficulty of the game is controlled by the speed of the balloons, the range of numbers displayed, and also the amount of distraction introduced into the background.

The budgeting game (Figure 5, top right) is a different way of testing Math skills. Here a student is given a budget to buy certain commodities. The student can click any item, which is individually priced, in the scrollable panel on the right and place it in the middle panel (shopping cart). The money spent on the selected commodities is displayed at the top of the screen. Crossword puzzles are used to test the vocabulary of a language as well as the semantics associated with a word. An example of such an item is shown in Figure 5, bottom. A student first relates a word with an image. By clicking on the image, the corresponding location of the word in the puzzle area is highlighted. The student then uses the virtual keyboard or the computer keyboard to spell out the word in the highlighted space.

5. An Overview of the CROME Multimedia Framework and its Innovative Components

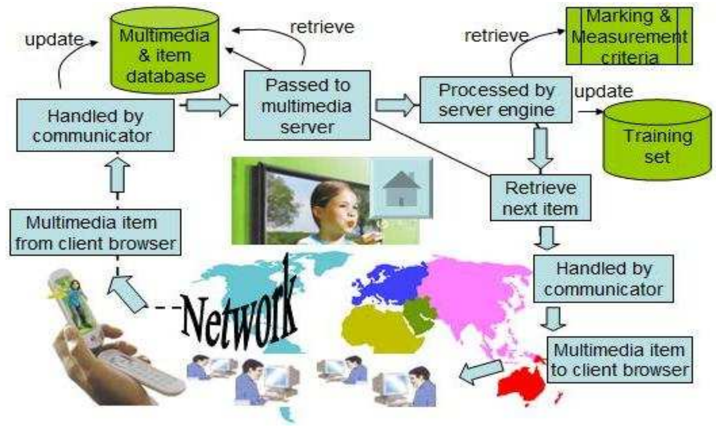


Figure 6: The multimedia data flow in the CROME framework.

Web-based multimedia systems can be used in a broad variety of applications, e.g. hurricane analysis and simulation [20]. CROME is designed for multimedia education and uses a combination of web-development tools in order to optimize the constrained resources and to provide user satisfaction. The development kits include Java 2D/3D applets, Javascript, Flash, J2ME, PHP and MySQL. SQL is an efficient query language used in many database retrieval systems [21]. The choice aims at platform and browser independence. While a Javascript item is fast to display, its 3D and animation capability is not comparable to Flash and Java3D. Flash animation is appealing but its 3D capability is not as good as Java3D. However, Java3D items need more programming skills for development, and can be slow during rendering when the content gets too complex. We choose one of these three for a particular item design depending on the complexity of the item and the intended outcome. The multimedia data flow in the CROME framework is shown in Figure 6. Among others, an important feature of our design is scalability. Similar to the multiple-choice format, a generic template is designed for each category of items, which share certain similarities. Multiple questions can be generated by altering the content inserted into the template. Furthermore, the layout, such as the number of objects and baskets shown in Figure 3, is controlled by parameters. This approach reduces recoding for individual questions.

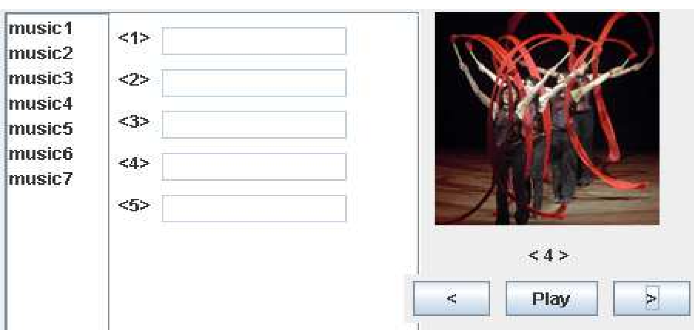
Automatic difficulty level estimation

In the multiple choice or true/false format, an answer can only be correct or wrong. There is no partial mark awarded. However, when multimedia content, such as 3D items are used in Computer Adaptive Testing, a student's performance can be evaluated more accurately by considering partial scores. In order to evaluate the correctness of an answer and award partial marks, we interpret a molecular structure as a graph, where nodes are atoms and edges are bonds. In this way, we can assess the correctness of an answer by comparing the similarity between two graphs. A number of graph similarity matching algorithms can be found in the literature. Among these algorithms, graph edit distance [22] is commonly used. In this algorithm, a set of graph edit operations is defined. These edit operations include deletion, insertion, and substitution of a node or an edge. The edit distance of two graphs is defined as the length of the shortest sequence of edit operations required to transform one graph to the other. In our scoring scheme, we extend the edit distance to a weighted version. A scoring matrix is used to store the weights. More details on this approach can be found in [23].

The graph based strategy for difficulty level estimation for chemistry questions discussed in [23] may not be applicable for other subjects. A parameter-based strategy is a more general approach for assigning initial difficulties to items. We use Math questions as examples to illustrate the concept. For example, when solving the question “distribute the numbers so that the sum in each bin is equal” (Figure 3, top), the difficulty level of a question is defined by a function $f(n_{bkt}, n_{nbr})$, where n_{bkt} is the number of baskets used and n_{nbr} is the number of objects to distribute. The difficulty level increases as n_{bkt} or n_{nbr} increases. We verified the feasibility of our approach by conducting evaluation experiments. We have shown that it is possible to predict the difficulty level of the items in Figure 3, top, by using a 2-Parameter Logistic Model following Item Response Theory (IRT) [24, 25] and estimating the parameters based on time taken to solve a problem by a small group of students using linear regression.

Details on this approach can be found in [26].

Testing Beyond Subject Knowledge



(a)

(b)

Figure 7: (a) An example of a musical item to test a student’s ability to perceive, express and transform musical forms, and (b) a sequence of video expressing different musical composition.

Conventional use of multimedia content in education focuses on subject knowledge but not on cognitive skills. According to Gardner, each person has seven intelligence aspects [27]: linguistic, logical-mathematical, spatial, bodily-kinesthetic, musical, interpersonal, and intrapersonal. By employing multimedia items, we are able to test a student’s broader range of skills. An example item to test one’s musical intelligence is shown in Figure 7. The idea in this item is to evaluate how well a student can associate body movements with musical rhythms. The student has to match the videos labeled from <1> to <5> with the corresponding musical clips. Each clip can be played by clicking a music button on the left panel. Details on this work can be found in [28].

Adaptive Testing and Student Modeling using Multimedia Items

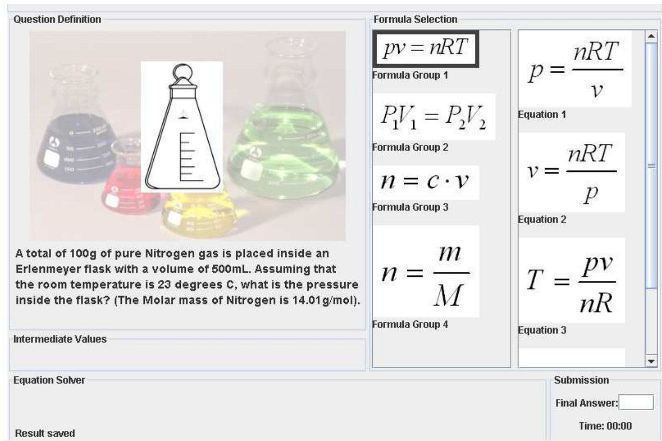


Figure 8: A Chemistry example: A screen shot of our Process Analyzer.

Complex and tedious processes are often encountered in curricula such as physics, chemistry, and mathematics, where the final answer is built upon the results of numerous smaller processes. We incorporate a Process Analyzer [29] in our CROME framework. The objective is two-fold: to assist students improve their problem solving skills using step by step hints and instructions, and to assist teachers in monitoring student performance so that proper help can be provided in time. The Process Analyzer defines the top-level process as the root of a hierarchy composed of simpler and easier steps so that students who have difficulty solving the problem on their own are able to follow the hints and instructions leading to the correct answer. The hints and the scores in each step are controlled by educators. Every response given by a student is recorded for performance analysis and student modeling. The Process Analyzer comes with a graphical user interface (Figure 8), which provides an engaging and motivating learning environment.

Each composite or simple question in the multimedia item pool is designed for a given grade level and is assigned a difficulty value. A student is evaluated based on their success in obtaining a pre-defined percentage of correctness when answering questions of a particular difficulty. During the process, a student can be given easier or more difficult questions, depending on whether his or her current response is wrong or correct. This approach of adaptively selecting the next item has been used in multiple-choice, true/false and fill-in-the-blank type of questions. Using multimedia items in adaptive testing is still a subject of research: there is significant complexity in assigning difficulty values to multimedia items, and in creating a sufficiently large pool of effective items to evaluate student abilities.

Following an adaptive testing strategy described above and a step-by-step record of a learner, a training set can be accumulated over time. Machine learning and artificial intelligence techniques can be applied to analyze data in the training set. Since different students require different types of assistance, teachers can customize their guidance based on individual learning patterns. In addition to evaluating a student's ability level, an important contribution of our design is the monitoring of a student's progress. Moreover, the training set contains valuable information for curriculum designers to fine-tune education materials. Note that the sense in which individual students are "modeled" is directly related to the richness of the items being investigated.

Multimedia Item Authoring Graphical Interface

In order to assist educators, who either cannot afford too much time in addition to their regular teaching or do not possess the required technical skills, to create new multimedia question items, we implemented multimedia item authoring templates. These templates are plug-ins integrated into the basic CROME framework. A screen shot of the authoring interface is shown in Figure 9. The authoring module can be run online for individual item upload, or offline for subsequent upload in a batch.

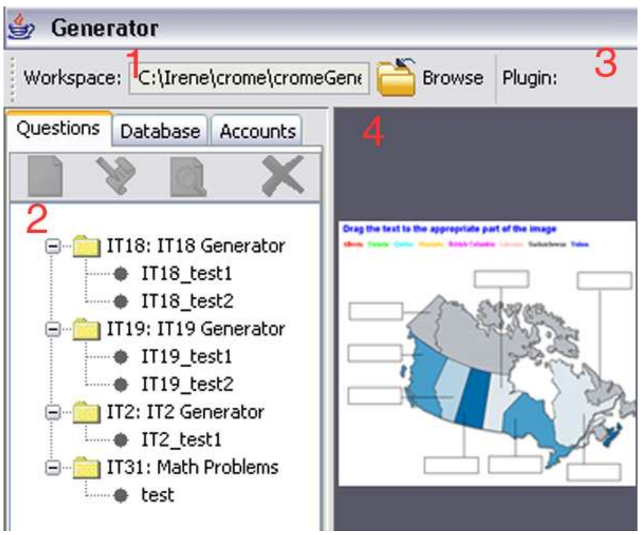


Figure 9: An example of the CROME authoring interface.

There are two main design challenges: First, the uniqueness of each innovative item type, and second, the need to provide different processing pipelines for online and offline item creation. Uniqueness of each item type means that each template has its own set of properties, and has its unique way of processing them. These challenges are overcome by separating the interface implementation into easy to manage logical components (Fig. 9). Although the authoring module is designed for educators, students can also use the tool to create questions, and through this process they will improve their understanding of the subject.

A demo of the CROME framework can be seen at [30].

7. Summary

In this article, we reviewed past and present trends in pervasive multimedia education. We showed with examples how the CROME framework was designed in order to address the vision of multimedia education anywhere, at anytime and for anyone. Although there is research in the literature focusing on certain target areas in education, our framework is unique in the way it incorporates automatic difficulty level estimation, item generation, process analysis and testing beyond subject knowledge. We optimize the available multimedia resources and development kits to implement portable and scalable education items that are appealing and entertaining to the learners.

Figure 10: Example item on a cell phone: (Top) A student needs to fill in the missing numbers so that the sum in each row and column is the same. (Bottom) Another item type "word scramble" showing the process of selection of alphabets to form the correct word.

The design of CROME aims to achieve portability, reusability, scalability and interoperability:

- Portability – The implementation is based on Java which is platform independent, including J2ME on mobile devices.
- Reusability – An object-oriented design makes individual components reusable.
- Interoperability – An authoring tool is an integral part of the CROME system, sharing the item type design, as well as media and item database.
- Scalability – New item type plug-ins can be added without the need to modify the basic framework or authoring module.

The example items presented in this article represent only a small portion of the pervasive multimedia ideas. Specific outcomes that cannot be tested purely using paper-and-pencil, such as inter-personal skills and remote collaboration, can now be tested in an online computer-based multimedia context. Using our framework as an initial step, we intend to bring awareness to the multimedia research community and to solicit effort in topics, which have not been adequately studied. In future work, we plan to develop collaborative learning environments over cell phones (Figure 10) that will allow students from anywhere around the globe to collaborate with anyone at anytime. Although cell phones have been extensively used for information exchange, making multimedia educational items available on cells in a collaborative learning and adaptive testing, given limited mobile resources including processing speed and bandwidth, is still a research challenge.

Acknowledgements

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