
An integrated e-learning system for simulation-based instruction of anaesthesia machines

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Abstract: Not all learners learn in the same way and at the same rate. Learners' learning styles that reflect their cognitive abilities vary in known ways; some prefer the traditional text-based or oral presentation of content, while others learn more easily in a visual or kinaesthetic instruction style. Simulation has been shown to be an effective way of teaching abstract concept, principle and process in many application domains. In this paper, we have developed reusable, interactive, simulation-based learning objects and designed and implemented an e-learning system called Gator E-learning System (GELS), to deliver the learning objects to learners in an interactive, adaptive and flexible manner. GELS integrates a web-based Virtual Anaesthesia Machine (VAM) Simulation System and a Collaborative and Dynamic E-learning Service System (CoDESS) for the purpose of teaching medical personnel the functions and operations of anaesthesia machines as well the preuse check of anaesthesia machines in a simulation-based learning environment.

Keywords: e-learning; learning management system; simulation-based learning objects; virtual e-learning community; adaptive learning.

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1 Introduction

Many multimedia data and application systems are available on the internet. They are valuable learning assets that can potentially be used for instruction purposes. Among higher education schools, over 90% of four-year public institutions and 88.6% of private institutions offer some form of e-learning (Allen and Seaman, 2004). In spite of many learning assets that are accessible on the web and the wide-spread advocacy of e-learning education, many teachers and students feel that the e-learning technology and learning assets still have not made a 'significant difference' in teaching and learning experience

(Alanis, 2004). The problem arises mainly due to two reasons. Firstly, learning assets on the web are not so easy to use for instruction purposes because they are dispersed and heterogeneous. A unifying mechanism that can make disparate assets useful learning resources is needed. Secondly, most existing e-learning systems are built to deliver static and text-based materials (SRI-Consulting Business Intelligence, 2003). Learning materials are presented to learners in forms of text, graph, figure, diagram and web pages. They are very similar to the learning materials presented in textbooks used in traditional classrooms. In a traditional classroom environment, learning tends to be a fairly lock-stepped, text-based experience.

Content presented in the form of visual and interactive simulation can be more suitable to some learners' cognitive abilities. Simulation has been playing an increasingly important role in education and training and has been used as the means of content presentation and delivery in many application areas. Abstract concepts, especially those related to phenomena that we cannot directly observe and/or manipulate in our daily lives such as stoichiometry, molecular shapes, gas laws and chemical bonding can be difficult for students to comprehend. Further, some experiments can be dangerous such as those involving concentrated sulphuric acid. Simulation in its different forms provides a safe and practical alternative when reality can be dangerous, expensive or opaque, or when an event occurs rarely or too slowly or too rapidly in real life. In these cases, simulations can be effective in teaching students these concepts. Simulation also produces a safe environment for learners to learn by making mistakes and being corrected. Learners can explore all possible scenarios not possible or acceptable in real world. Some of the best learning comes from many trials and errors. In the medical field, simulation presents a risk-free learning environment without the fear of harming a human life. Well-designed simulations often significantly reduce training time and cost. Simulation can bring a unique learning experience with the higher learner satisfaction, especially in professional training (Chapman, 2006; Lunce, 2004). They allow learners to manipulate any displayed object of interest and view and study the object from different angles and perspectives or to observe the changes of a physical process over time using visualisation and animation techniques. Furthermore, a learner's interactions with the displayed object (e.g. mouse clicks) can be tracked, recorded and used by the system to determine the state, progress and comprehension of the learner in a learning process.

Text-based e-learning does not provide a learning environment for learners to practice on what they learned from content. It also provides limited means for assessment. The typical forms of assessment in text-based e-learning are simple questions and answers or multiple choice questions so that an e-learning system can easily determine learner's progress. Simulation can be used, not only for presenting content, but also for practice as well as for assessing the learner's domain competency by tracking learner's interactions with a simulator in a simulation-based learning environment.

In this paper, we present an integrated e-learning system called Gator E-Learning System (GELS). This system integrates two systems that were separately developed: a Virtual Anaesthesia Machine (VAM) Simulation System and a Collaborative and Dynamic E-learning Service System (CoDESS). VAM is a web-based simulator of a generic anaesthesia machine developed by the Department of Anaesthesiology at the University of Florida (Lampotang et al., 2006). It is a visual, interactive simulation system with model-driven, real-time animation of colour-coded molecules and dynamic representation of flows, pressures, volumes and concentrations of gases. It is also a

transparent simulator, which can display the internal, abstract and invisible functions of the anaesthesia machine. CoDESS is an event-trigger-rule-based e-learning service system developed at the Database Systems R&D Centre (Lee and Su, 2006; Su and Lee, 2003, 2004). In this work, instructional materials developed for VAM are transformed into simulation-based learning objects by using the authoring tools provided by CoDESS. These learning objects are then processed by a Learning Process Execution Engine (LPEE) (a key component of CoDESS), which delivers content to learners and in one application, activates VAM's simulation facility for practice and performs assessment. In another application, VAM is used for simulation-based content presentation, practice as well as assessment. The assessment result is given to the LPEE to customise and adapt a learning process to suit the learner's profile, competency and progress. The integrated system is designed for use by medical personnel to learn normal functions and operations of anaesthesia machines as well as FDA's preuse check of traditional anaesthesia machines in a simulation-based learning environment.

This paper is organised as follows. Section 2 describes GELS's system architecture. Section 3 discusses the ways atomic and Composite Learning Objects (CLOs) are modelled using authoring tools. Section 4 presents the simulation-based learning objects developed for two applications in medical instruction. A summary and a conclusion are given in the final section.

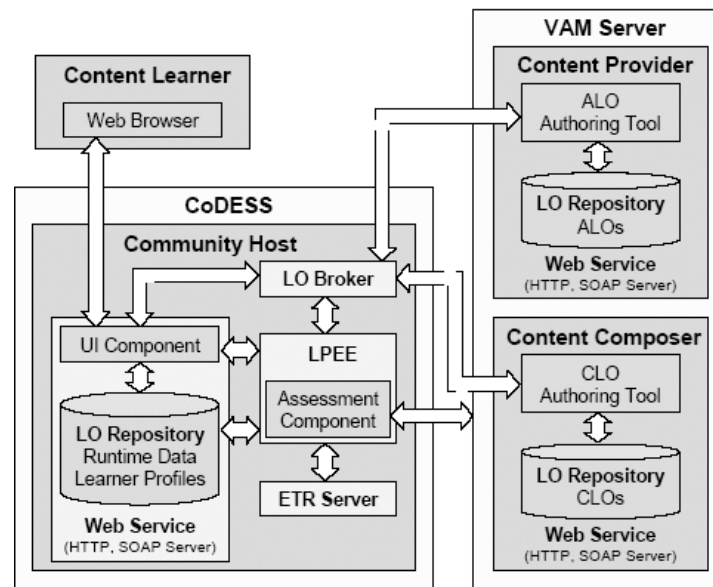
2 System architecture of GELS

Figure 1 shows the overall architecture of GELS and the interactions of its two component systems: CoDESS and VAM. CoDESS consists of a number of replicable components that enable the creation of multiple virtual e-learning communities over the web, each of which can be formed by a group of internet users who are interested in a specific topic of learning (Su and Lee, 2004). A member of a virtual e-learning community can play one or more of the following roles:

- 1 content producer (an expert on an instructional topic), who constructs Atomic Learning Objects (ALOs) by using multimedia learning assets created by him/her and/or accessible from the web and register the metadata and constraint specifications associated with these ALOs in an LO registry of the community
- 2 content composer (also a domain expert), who composes CLOs by reusing or repurposing the existing ALOs and CLOs (more details about ALO and CLO will be given in Section 3) and registers their metadata and constraint specifications in the same LO registry
- 3 content evaluator, who evaluates ALOs and CLOs and posts the evaluation results at the host site for other members' browsing and querying
- 4 administrator of the community host site, who maintains the software system installed at the host site and performs management functions of the virtual community
- 5 learner, who provides the system his/her profile information when he/she registers with the system, searches for suitable LOs registered in the registry and receives instruction and assessment online and

- 6 instructor (who may or may not be a content producer/composer) who uses the developed LOs and GELS to teach learners and monitor their progress and performance.

Figure 1 Architecture of GELS



An ALO authoring tool and a CLO authoring tool are installed at the network site where the VAM simulation system is located. They make use of the instruction materials and simulation facilities of VAM to construct ALOs and CLOs, respectively. These authoring tools can be installed at a large number of network sites and be used by many content producers and composers to construct ALOs and CLOs. The constructed ALOs and CLOs are stored in repositories at the sites where they are created. They are ‘wrapped’ as web services and their metadata, service constraint specifications and access point information are registered with a Constraint-based Learning Object Broker (LO Broker) installed at the host site. The LO Broker provides browse and query facilities for community users to discover, locate and activate the distributed learning objects. It performs constraint satisfaction processing to match a user’s search requirements against the metadata and constraint specifications of LOs to find the suitable LO for the user.

In addition to the LO Broker, the other key components of CoDESS are: LO Repository, User Interface Component, LPEE, Event-Trigger-Rule (ETR) Server and Assessment Component. The LO Repository at the community host is used to store the LOs fetched from remote LO repositories in response to users’ requests so that they can be processed locally to achieve better efficiency. It also stores learners’ profile information provided by learners when they registered with the system to become members of a virtual e-learning community. The repository also stores and maintains learners’ progress and assessment results. The User Interface Component facilitates the communication between learners and other system components. The first-time user of GELS is asked to provide his/her profile information to the system. After a learner logs on the system, he/she can search LOs, save the access points of these LOs in the learner’s

space for later execution, start/resume the processing of LOs, update learner profile and retrieve the current status of the LOs that he/she is taking through the user interface component.

The LPEE processes LOs using an event-trigger-rule-based execution model (Lee and Su, 2006) to achieve active, adaptive, flexible and customisable e-learning services. The ETR Server (Lee et al., 2001) is an ETR processing engine, which is responsible for the execution of sequencing rules to customise and adapt a learning process to suit each learner's profile and progress. The Assessment Component assesses the progress and performance of a learner in a learning process by presenting problems to the learner and accepting answers from him/her or by monitoring the learner's interactions with the simulator to perform interactive assessment. The assessment results of learning activities constitute the runtime status model of the learner, which, together with the learner's profile information, are used by LPEE to control the learning path; that is, the next step of instruction delivery and assessment. Thus, assessment in our system is an ongoing not episodic process. It makes the learner's learning path flexible and adaptive.

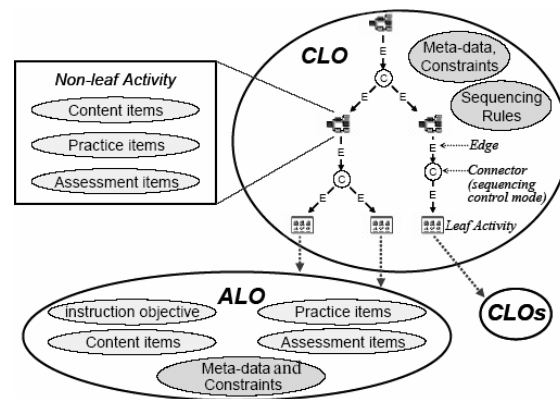
3 Learning object models and authoring tools

We have introduced two LO models and their accompanying authoring tools (Lee and Su, 2006; Lee et al., 2004). These models extend the modelling features of SCORM's activity trees (ADL, 2004) and Cisco Learning Institute's Reusable Information Objects (RIOs) and Reusable Learning Objects (RLOs) (Barrit, 2001; Termaat et al., 2004, 2005). *The Learning Content Definition Model* and its accompanying authoring tool are designed for use by content producers to define and construct ALOs. An ALO is a unit of instruction that a content producer regards as atomic (i.e. non-decomposable and self-contained). It has a well-defined objective and contains content item(s), optionally practice items and assessment items (see Figure 2). Each item can be a multimedia learning asset (text, graph, image, video, audio, simulation, game or a web page that contains a variety of assets), which is either prepared by the content producer of the ALO or accessible from the web through its URL. Additionally, an ALO has metadata and constraint specifications associated with it (e.g. the language used is Spanish, the targeted learner group is middle school students, etc.). They are registered with the Constraint-based LO Broker, which provides browse and query services for users to find their desired LOs.

The Learning Process Definition Model and its accompanying authoring tool are used for modelling CLOs. A CLO is modelled by a tree structure of activities similar to the activity tree proposed in SCORM but with three major improvements (see Figure 2). Firstly, any non-leaf learning activity (just like a leaf activity) can have content, practice and assessment items, which are not allowed in SCORM. The advantage is that the content items may give an introduction and/or summary of the content presented in the subtree rooted at the non-leaf activity and the practice and assessment items are used to exercise and assess the integrated knowledge learned from the subtree. Secondly, a new modelling construct called 'connector' is introduced to connect a parent activity to a number of child activities. Sequencing control modes adopted from SCORM's Sequencing Definition Model (ADL, 2004) define the sequencing behaviour among child activities, such as delivery in sequence or user's choice. The connector also stores the specification of sequencing control mode; thus changes made to the sequencing control

mode in the connector will not affect the activity specifications. This separation of control information from activity specifications is needed to achieve the runtime modification of sequencing control modes based on a learner's profile and progress without affecting the activity specifications. Available sequencing control modes are discussed in ADL (2004). Thirdly, a leaf-activity may either make reference to a specific ALO or CLO or contain a request for an ALO or CLO. In the former case, the leaf activity is statically bound to an LO. In the latter case, the request is dynamically bound to a suitable ALO or CLO using the constraint processing facility of the Constraint-based LO Broker at runtime. The learning process model defines the process of delivering instruction to learners in a structured way that is designed by its content composer to suit most learners. However, when it is used to deliver instruction to a learner, the sequencing control modes specified in an activity tree and even the structure itself can be customised and adapted at runtime to suit the learner's profile and progress using the event-trigger-rule-based processing of a CLO. At various stages of processing an activity of a CLO (e.g. right before processing an activity, after preassessment, after content presentation, after post-assessment and before leaving an activity), the system would post events to trigger the processing of some relevant sequencing rules. These rules make use of the profile information and progress status information of the learner to determine the proper sequencing control mode and the learning path through the activity tree that are suitable for the learner. Thus, sequencing rules are applied within the processing of each activity rather than just between activities as in SCORM's activity tree.

Figure 2 The structures of ALO and CLO



4 Simulation-based e-learning objects and their applications in medical instruction

Hospitals and clinics use complex medical equipment on a regular basis. The safety of the patient relies on the proper interaction between a skilled practitioner and the equipment (Dalley et al., 2004). Unfortunately, a human practitioner's mistake is a dominating factor in up to 90% of the problems caused by the equipment (Weinger, 1999). To educate a medical practitioner or student, it is necessary to focus on teaching him/her both the domain knowledge about the equipment as well as its associated skills in order to make him/her a proficient practitioner in the medical field.

The VAM Simulation System was designed and developed to offer simulation-based instruction to medical personnel the function and operation of anaesthesia machines. Two simulation-based applications have been developed. The first one was designed to teach the normal function and operation of traditional anaesthesia machines and the second one was designed to teach the preuse check of anaesthesia machines recommended by FDA.

4.1 Normal functions of traditional anaesthesia machines

In VAM, the instructional material for teaching the functions of anaesthesia machines is in the form of a workbook, which is accessible to learners through the web site provided by the Department of Anaesthesia at the University of Florida. The workbook is like a text or training manual. It was not designed based on learning object design principles. The content of the workbook is monolithic; it is not partitioned into reusable instructional modules with their corresponding assessment items and well-defined objectives. Although, some remarks are made in the workbook to suggest learners the order of studying the workbook, a learner can explore any part of the workbook without any restriction. This may be suitable to some learners but others may need more structured and guided instruction delivery.

After studying the workbook, a learner can activate the VAM simulator to practice on what he/she learned from the workbook by, for example, turning the dials or opening or closing the valves of the machine to see the effect of gas flow. After the practice, the learner is instructed to visit a separate quiz website to be assessed of the knowledge and skills learned. The workbook, the simulator and the quiz were separate entities. They were not integrated to provide learners a seamless learning experience.

In this paper, we make use of the content provided in the existing workbook and the quiz questions to construct a number of ALOs. We then define a CLO as an activity tree, which aggregates these ALOs. The workbook consists of the following three parts. Part 1 introduces the basic concepts related to a general anaesthesia machine. Part 2 introduces how the VAM simulation works. Part 3 covers specific safety-related exercises about six subsystems of an anaesthesia machine: the High Pressure System, the Low Pressure System, the Breathing System, the Manual Ventilation System, the Mechanical Ventilation System and the Scavenging System. The CLO that aggregates these three parts is shown in Figure 3. In this activity tree of the CLO, the contents of parts 1 and 2 are used as the content items of two ALOs, respectively and the contents of the six subsystems of part 3 and their associated quiz questions are used as the content items and assessment items of six ALOs. Each of these ALOs contains practice items which describe a demonstration scenario related to the content and provides a web link for invoking the VAM simulator so that the learner can use it to practice on what he/she just learned from the content by following the demonstration scenario using the simulator. Thus, a learner can study the content of an ALO, use the VAM simulator for practice and be assessed of the knowledge and skill acquired in a seamless fashion under the control of the LPEE of CoDESS. In Figure 3, the non-leaf activities labelled 'VAM' and 'Part3_safety_exercises' have content items to introduce and summarise the content presented by the subtrees rooted at these activities. Their assessment items would assess a learner's ability to integrate the knowledge and skills learned from the ALOs of the subtrees.

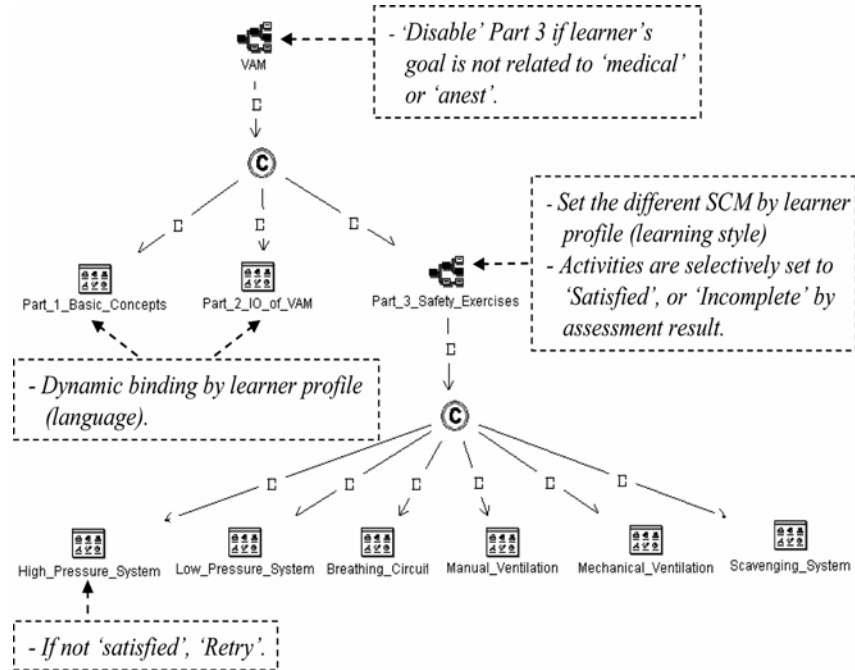
Figure 3 Activity tree that models VAM

Figure 3 is also intended to illustrate the customisation and adaptation capabilities of CoDESS. As we mentioned in Section 2, CoDESS uses an ETR processing mechanism to process a CLO to customise and adapt the learning process to suit individual learner's profile and progress. For example, a rule associated with the root node VAM checks if the stated learning goal (a part of learner's profile) is to learn something related to medical instruments in general or to anaesthesia machines in particular. If so, the detailed information about the various subsystems under the non-leaf node Part3_Safety_Exercises will be presented to the learner. Otherwise, the entire subtree will be deactivated.

The activity tree can make requests for dynamic bindings to LOs at runtime. For example, a leaf activity will check a learner's preferred language specified in the learner's profile and binds a request dynamically to an ALO written in his/her preferred language. Also, a sequencing control mode specified in the Connector (marked by 'C' in Figure 3) determines the order, in which the child activities under it can be selected by the learner. By introducing a rule, which checks for learner's preferred instructional strategy (e.g. one of the four strategies introduced by Clark (2000): receptive, directive, guided-discovery and exploratory) and sets the proper sequencing control modes, the system can control the degree of freedom that the learner has in selecting the child activities to process and in determining the order of their processing (i.e. delivery of content). Furthermore, rules can be designed to affect the learning path that a learner should take based on the results of assessments. For example, a rule may require a learner to retry an activity if the learner failed to achieve a satisfactory score in the assessment of the activity, Part3_Safety_Exercises. Or, if the learner

achieved satisfactory scores in more than 3 child activities, the assessment in Part3_Safety_Exercises will not be presented. Some rules that facilitate the dynamic execution of the CLO are shown in Figure 3.

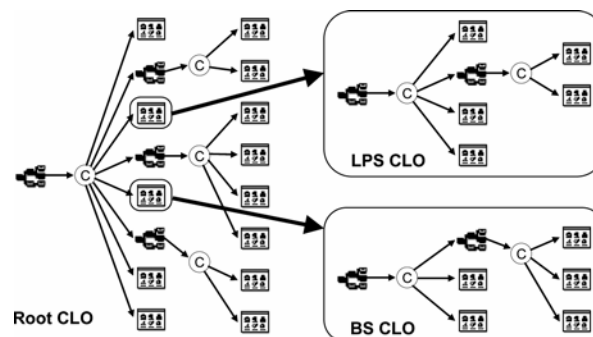
4.2 FDA's preuse check of traditional anaesthesia machines

FDA's preuse check of traditional anaesthesia machines is a checklist that a person who will operate an anaesthesia machine must go through to ensure that the machine is perfectly functional and safe before it is used on a patient. Although the FDA checklist is only one page long in writing, each step in the checklist can require the user to perform rather complicated operations on an anaesthesia machine. Our task therefore is to develop simulation-based learning objects and use GELS to teach medical personnel the steps in the preuse checklist. To achieve this, we need to first design ALOs and CLOs that provide instructions needed for the checklist and then to find the best way of using simulations to present content, facilitate practice and perform assessment.

Our design of LOs is guided by the design principle that each ALO represents a self-contained and reusable object and each CLO aggregates a number of related ALOs and is also likely to be reused in the instruction of other related medical devices. The activity tree that models the CLO to capture the instructional content of the checklist is shown in Figure 4. The tree contains four non-leaf activities and 13 leaf activities. Two of the leaf activities are bound to two CLOs, which cover the preuse checks of the Low Pressure System (LPS) and the Breathing System (BS), respectively. The other leaf activities are bound to ALOs, each of which provides content, practice and assessment items to instruct and assess the preuse check of one part of an anaesthesia machine. The activity tree serves to illustrate that one can aggregate ALOs to form a CLO and the CLO can in turn link to other CLOs to form a more complex structure. All ALOs and CLOs are registered with the LO Broker, which provides browse and query facilities.

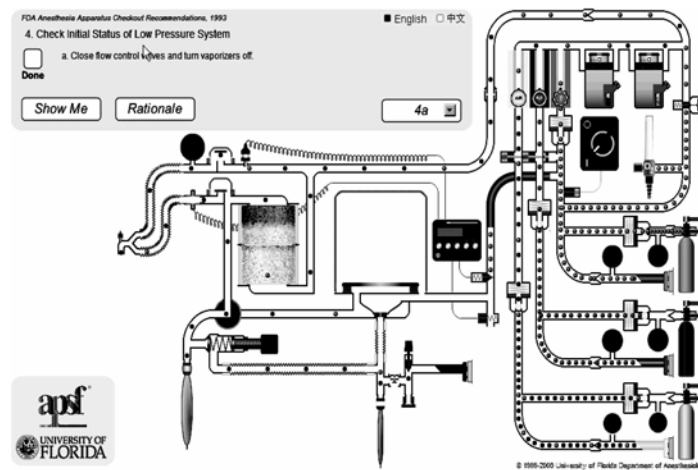
In the application described in Section 4.1, we use the VAM simulator to offer learners an environment to practice on what they learned from content. In this second application, we use simulations not only to present content, but also to facilitate practice and perform assessment visually and interactively. The processing of each ALO shown in Figure 4 is carried out in three steps: See one, Do one and Test one.

Figure 4 Activity tree that models the checklist



The step ‘See one’ displays the VAM simulator that is to be checked. A ‘show me’ (i.e. a ‘play’) button, when clicked by the learner, will show the actions of an expert who operates the machine properly to perform the preuse check of that part of the machine instructed by the ALO. By observing the expert’s actions and the effects of the actions on the simulator, the learner can develop his/her own cognitive knowledge and skills on the machine. Figure 5 shows a snapshot of what the learner sees at this first step.

Figure 5 VAM simulator at the ‘See one’ step



The step ‘Do one’ is a practice step designed to let the learner redo the steps that ‘See one’ showed. It enables the learner to solve problems on his/her own with the help of some tutorial messages. Although, the learner operates on the same simulator as the one shown in the ‘See one’ step, in ‘Do one’, the learner can operate the simulator without any limitation because all icons are activated. The learner is free to try out different things and to find the correct procedure by trial-and-error. When a mistake is made, the learner gets an immediate feedback on his/her action. If a learner makes a sufficient number of mistakes, the simulation will take over and shows the ‘See one’ operation again to the learner.

‘Test one’ is an assessment stage for testing the learner’s competence and retention of the domain knowledge and skills. The simulator leads the learner to make a mistake by giving a faulty or a perfect machine at random and then provides the assessment result as a delayed feedback after the learner’s work is assessed. Since all parts of the simulator are operable, the learner is free to do anything to solve the problem given to the learner. ‘Test one’ aims to identify and correct the misconceptions acquired or gaps left in earlier steps.

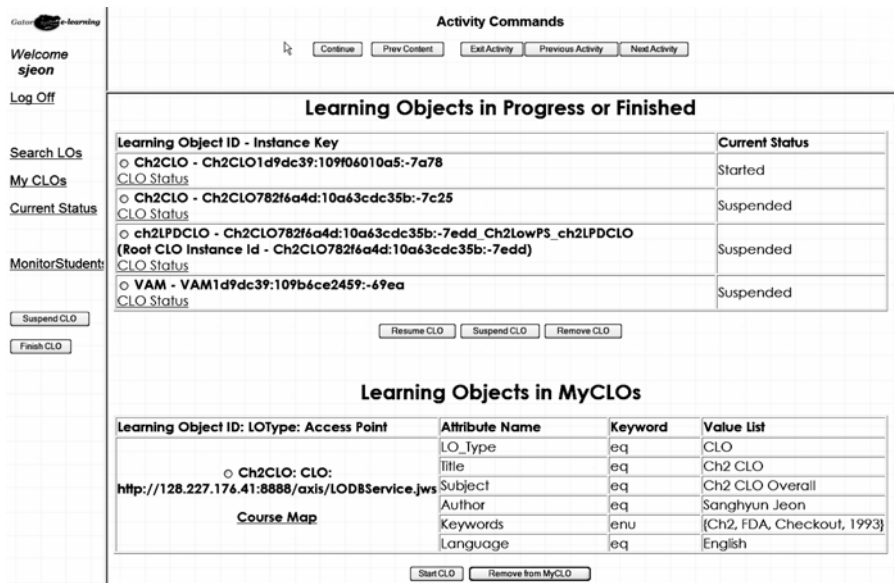
Simulation-based assessment gives a chance to the learner to review what he/she learned, correct misconceptions and reflect on his/her progress. The ‘Test one’ step is done by learner’s mouse clicks and is tracked by the VAM simulator to determine if the learner is following the correct steps. This method of ‘interactive assessment’ is very different from the traditional approach of assessment which uses simple multiple/choice and fill-in-the-blank questions. It is effective in a simulation-based learning environment.

The assessment result collected by the VAM simulator is passed to the assessment component of CoDESS, which records and uses the assessment result to control and carry out the subsequent processing of the CLO developed for the preuse checklist.

4.3 Other facilities of GELS

Additional facilities are provided to ease the task of learners in their use of GELS. A learner can query the Constraint-based LO Broker through a search user interface to find his/her desired CLOs. The search conditions specified through the interface is used by the Broker in a constraint satisfaction processing to discover the desired CLOs. The CLOs can be stored in a learner space, called 'MyCLOs', which contains all the CLOs that have been selected by the learner and their processing statuses. The status information associated with these CLOs can be used to track the learner's history of learning. Figure 6 shows the user interface for the MyCLOs.

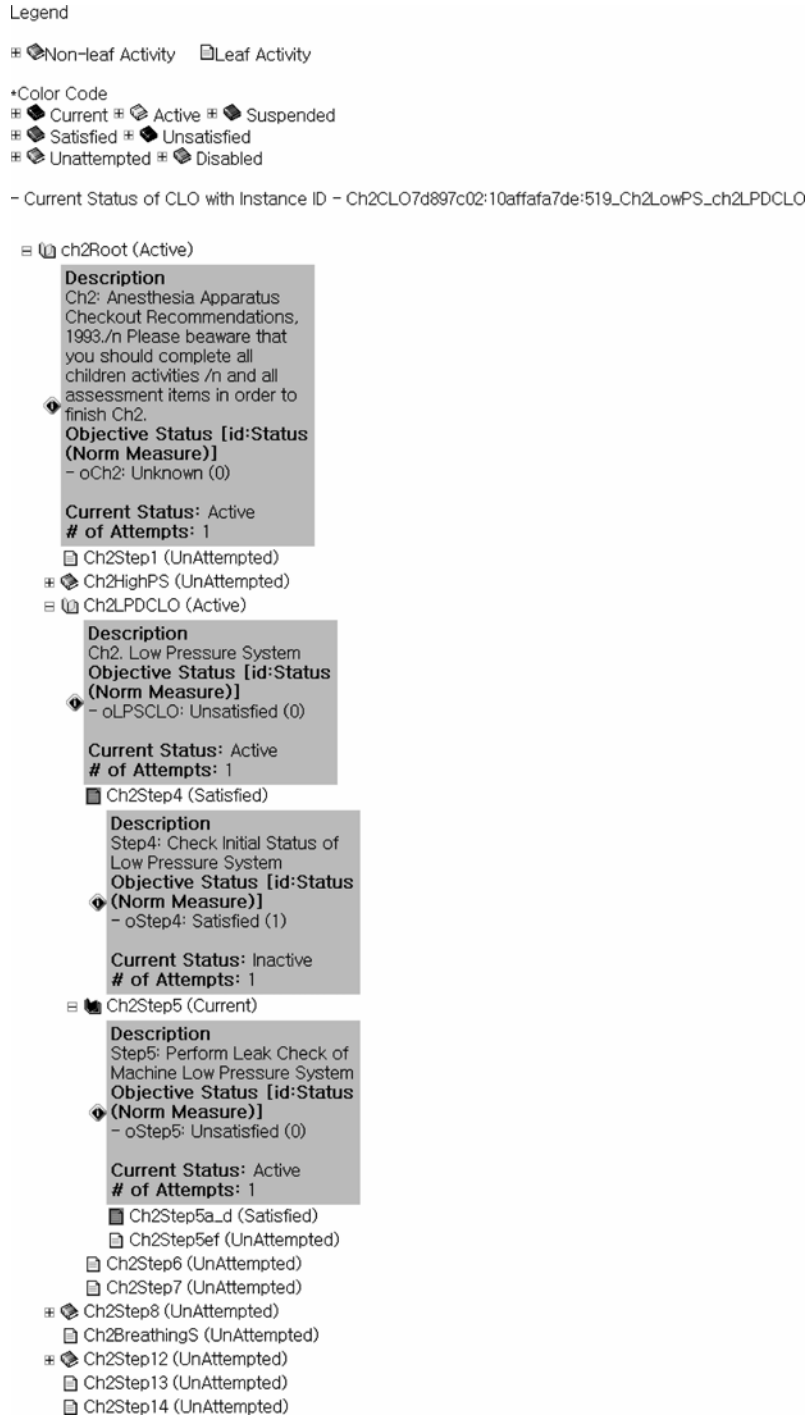
Figure 6 User interface for the MyCLOs



GELS also provides a 'MonitorStudent' facility to an instructor, who can monitor the progress and performance of all the learners who signed up for the instruction of a CLO. This information is also very useful to LO developers in their design of additional LOs or their modification of the existing LOs. 'CurrentStatus' is a facility for displaying a colour-coded map similar to a table of contents as shown in Figure 7. The map shows the learner the activities and their statuses. The status information include activity satisfaction status (satisfied/unsatisfied), status of learning objectives (score, satisfied/unsatisfied), number of tries, etc.

'Learner Profile' is a registration user interface, which gathers a learner's profile information including demographic information, learning goals, preferred language, preferred learning style, prior knowledge, learning history, etc.

Figure 7 CLO status monitoring information



5 Summary and conclusion

We have presented the GELS which integrates two systems that have been separately developed: the VAM Simulation System and the CoDESS. The architecture, the learning objects models and their accompanying authoring tools and two applications of the integrated system have been described.

The system is developed for teaching medical personnel the function and operation of anaesthesia machines and the preuse check of these machines. In the first application, we make use of the resources of VAM, which include the VAM workbook, the VAM simulator and quiz questions and the authoring tools provided by CoDESS to develop learning objects. These objects are used by CoDESS to deliver content, activate the VAM simulator for practice and perform assessments. In this application, we also show how the ETR processing mechanism of CoDESS is used to customise and adapt learning paths in a CLO to suit a learner's profile and progress. In the second application, we demonstrate the use of the VAM simulator to, not only deliver content visually, but also facilitate practice and perform assessment. A learner's interactions with the simulator are tracked and recorded to determine his/her progress and the knowledge and skill acquired. The assessment result collected by the VAM simulator is passed to CoDESS, which controls the processing of the CLO developed for the preuse checklist. By integrating these two systems, we are able to take advantage of the simulation-based instruction and learning offered by VAM and the adaptive, customisable and flexible properties offered by CoDESS to deliver individualised instruction to learners. The developed ALOs and CLOs in these two applications are reusable. They can be used for the instruction of some other medical machines or devices, which have some of the components of an anaesthesia machine.

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