Virtual Apparatus Framework Approach to Constructing Adaptive Tutorials

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Abstract - *We present the Adaptive eLearning Platform (AeLP) – a platform solution for creating rich, interactive, and highly visual, adaptive eLearning activities designed using Virtual Apparatus Framework (VAF). We piloted the AeLP during 2006 at the School of Physics at the University of New South Wales (UNSW), where four adaptive tutorials were embedded into the first year physics syllabus and were completed by over 300 students. The fundamental design decisions we employed in developing the AeLP had to meet the following requirements: (1) to promote reusability of learning objects by adhering to strict separation of content and presentation; (2) to allow for rapid prototyping and deployment of eLearning activities across many domains; (3) to deliver adaptive feedback and adaptive sequencing of activities based on the student's model. We chose VAF as the design and development methodology to meet those requirements in developing eLearning modules for first year physics laboratories. This paper gives an overview of AeLP focusing on VAF development processes and capabilities, and describes its deployment in the University of New South Wales. Our initial results working with the AeLP during 2006 indicated that the entire content development cycle can take less than one week to create a rich, interactive and adaptive tutorial using VAF. We also found reusability to be very straight forward. We believe that VAF is a potential paradigm shift in eLearning material development methodologies.*

Keywords: Adaptive eLearning, e-Learning design and methodologies, Intelligent Tutoring Systems, Content Re-Use, Virtual Apparatus Framework.

1 Introduction

Many research and development streams in the field of eLearning revolve around two fundamental questions: (1) how can previously developed material be cost-effectively reused in different educational context? and (2) how can we intelligently adapt the content delivered to the learner's level of knowledge? The former, emerged as a reaction to the practice of hardwiring eLearning material. This practice stems from the complex nature of software programming where, typically, while developing learning objects (LO's), the pedagogical aspects of the learning activity are hard-coded into the learning objects. For example, texts and numbers might be embedded in source code and can only be revised by the developer. Furthermore, the educational flow of the activity is usually complex and needs to be storyboarded in advance. Therefore custom-built LO's are difficult to re-use in different contexts [3]. As solutions for this problem, several frameworks were researched and developed. Some addressed the issue by creating educational resources databases that were indexed with metadata ([7],[8],[14]), and some solutions attempted to standardize approaches to developing reusable LO's by means of specifying packaging standards, delivery methods, and communication protocols between the different components of the eLearning systems [13] or offer architectures that promote content reusability [11].

The latter question, i.e. – how can content be adapted to student's knowledge level, is the research question of such fields as Adaptive eLearning ([9],[1]) and Intelligent Tutoring Systems ([10],[12]).

The AeLP is a research direction fusing these two questions that was originally designed to provide multimedia support for first year physics courses at the University of New South Wales. Since 2004, the first year physics teaching at UNSW was reformed to incorporate "Exploratorial" sessions which are described as:

> A lecture is where you learn the theory. A tutorial is where you learn to manipulate the equations. A lab is where you measure things. The Exploratorials' aim is to integrate observations, experiments, calculations and theory. They aim to offer the insight of a lecture, the student-led analysis of a tutorial and the hands-on measurement of a lab, and will be supported with a range of media [6].

The multimedia eLearning component of the Exploratorials sessions had to be: (1) reusable so they can fit into the dynamic nature of a changing syllabus, (2) highly visual to meet challenges typical to physics teaching where visualizations and experimentation play a crucial role in learning, (3) interactive so as to promote guided user exploration and discovery, (4) easily edited, revised and updatable by a non technical teacher and (5) be pedagogically sound by providing intelligent remediation and feedback.

To meet those requirements we developed the Adaptive eLearning Platform – a set of technologies, software tools, business and development processes and web services that support the development and deployment of adaptive eLearning content. The pedagogical linkage to the physics lab teaching paradigm manifested itself in the design choice of our solution: using Virtual Apparatus Framework for constructing adaptive eLearning activities.

One of the incentives to develop the AeLP is a desire to create a better student learning environment. Research to date ([15],[16]) suggests that students benefit from an interactive learning environment in which they can have some control of their learning experience. Teachers will also benefit from the ability to track the students' progress during the learning activities.

This paper will describe the VAF approach for constructing adaptive eLearning activities and will discuss how our solution meets the two abovementioned issues of reusability and adaptivity.

2 Virtual Apparatus Framework for Designing and Developing eLearning Activities

Virtual Apparatus Framework was proposed as a model for authoring virtual experiments in web-based courses[5], and as a framework for interoperability of VA's in web-pages. We have employed VAF as a process centric approach to develop adaptive eLearning tutorials. This section will discuss how this was achieved. Our discussion of VAF will be in the context of physics, but note that VA's can be designed in other domains and that this is part of our ongoing work and will be discussed under Future Work below.

2.1 Physics Lab Metaphor

A good starting point to discuss VAF is to examine a real world example of creating a lab based educational activity. We will briefly examine the process of setting up a Faraday's Law experiment in a typical University Physics and Engineering teaching lab [see Figure 1]. This experiment is common place in first year teachings of many engineering and science courses. To set up this experiment in a laboratory, the teacher usually follows the following process:

- Getting the apparatus – in this case the teacher will need a magnet, a copper coil, a voltmeter and typically an oscilloscope and/or a PC with particular software tailored for this experiment. The teacher or the school will need to purchase the apparatus.

- Setting up – the apparatus needs to be constructed on the experiment table in the lab in a way such that novice students will interact with it. Thus the teacher must initially set up the experiment, check that it works and leave some things for the students to calibrate.

- Composing notes – once the experiment table is set up, the teacher composes experiment notes, which contain the educational aspects of the lab work.

In this example, it is important to notice that:

- The teacher did not build the apparatus – s/he did not program the computer software nor did s/he build the oscilloscope.

- The apparatus does not contain any educational content – the magnet did not come with questions and tasks attached and the oscilloscope did not come with explanations about its physics. Thus, there exist a proper content and presentation separation in the process.

- The apparatus is reusable –any piece of apparatus can be used in different experiments

- The notes are editable by the teacher – if a typo exists in the text, or if some parts of the experiment must to revised, edited or omitted altogether - the teacher can change the notes at any time and give the students a different copy to work with.

The educational aspect of the laboratory work only came into being when the teacher put together the different apparatus and added the notes.

2.2 Developing Learning Objects in Virtual Apparatus Framework

Virtual Apparatus Framework for developing Learning Objects employs a similar content development paradigm as the real world example described above with an emphasis on separation of presentational content development and educational content authoring.

At the heart of VAF is the concept of Virtual Apparatus. For our purpose, virtual apparatus are software based equivalents to real lab discrete apparatus, or complete Virtual Experiment (VE) setups. Content development in VAF consists of importing prefabricated Virtual Experiment setups into the system, setting them to some initial state, and then composing notes that will direct the students through their interaction with the VE. For each VE that is imported, we compose a set of questions that require interaction and explorations of different types from the students (e.g. "set the apparatus to such condition to achieve maximum flux through the coil"). We do not give students just multiple choice or input questions, we give them tasks that require interaction. The teacher defines the "correct state" the apparatus should be brought to, and some error traps with feedbacks and the system manages the interaction with the students.

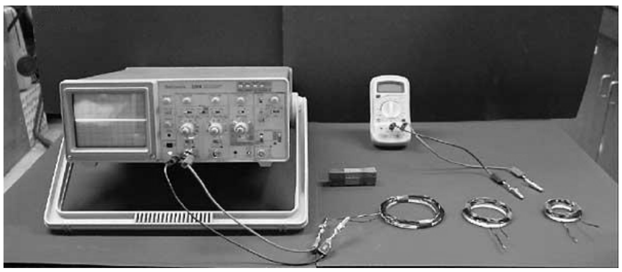

Figure 1 - Faraday's law experiment setup in first year Physics laboratory includes an oscilloscope, coil at different diameters, magnets of different strengths and a voltmeter

2.3 Application Programming Interface for Virtual Apparatus

Real lab apparatus [Figure 1] comes with an interface, for example, buttons, knobs and sliders that control apparatus functionality. When the teacher initially sets up the experiment s/he sets the different apparatus to an initial state, and typically instructs the students in the experiment notes to manipulate the apparatus to achieve a desirable outcome in terms of a final state. Similarly, Virtual Apparatus is built with an interface, so VA's can be used in different contexts in different ways by manipulating their states via their Application Programmable Interface (API). For example, the Faraday's law Virtual Experiment [Figure 2] might support some basic configurable interfaces that might control the strength of the magnet. Thus a teacher might devise an activity where first the students are asked to explore the physical phenomenon as the VA is set to particular magnet strength and answer some questions about it. Then for the next activity the magnet strength is changed and different questions are asked.

The API is designed such that it is possible to *GET* and *SET* values of different properties and variables of the VA. In our example, the Faraday's law VE contains a control of type Slider called *angleControl* (which, as the name suggests, controls the angle of the coil in the visualization), that has several parameters that can be *SET* or *GET*. For example the *SET* statement:

- *VA.angleControl.value = 15*

will set the value of the slider to 15 units.

When a VA is imported into the platform a "handshake" protocol is initiated between the platform and the VA and the platform creates an Object Model interface to the VA's properties it can access [Figure 3].

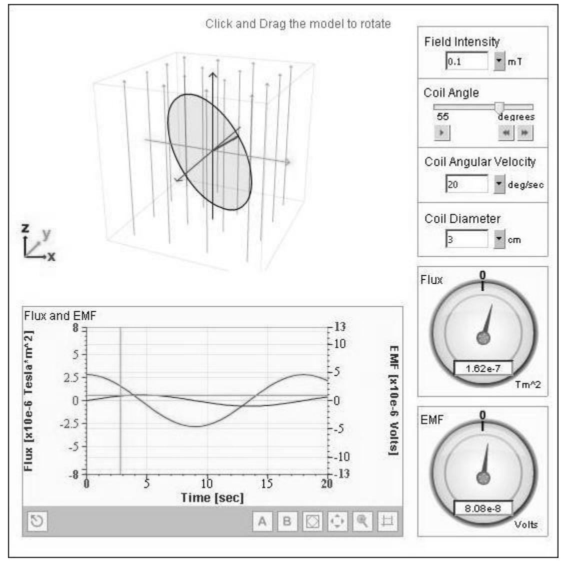

Figure 2 –Faraday's Law Virtual Experiment consists of an interactive 3D model, simple controls (sliders) and advance scriptable VA's (oscilloscope and meters). Each component in the visualization is a VA. The entire experiment is considered a VA as well

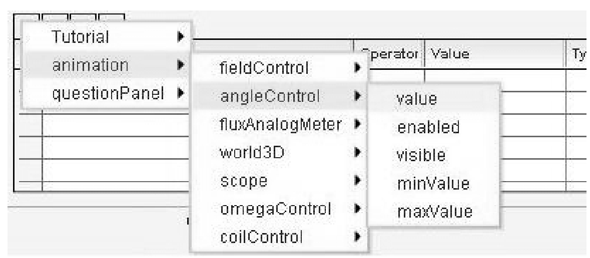

Figure 3 – The VA exposes its Object Model to the AeLP. The Platform's question Panel's Object Model and the history Object Model (Tutorial) are queryable as well

2.4 VAF Content Development Process

Using VA as building blocks for eLearning tutorials entails adopting a Laboratory-like teaching paradigm for designing eLearning activities. We thus need to think in similar pedagogical terms as designers of experiments in teaching laboratories, e.g. – "investigating what phenomenon and engaging in what tasks will teach the students the desired concepts"?

When developing content for the AeLP, we identify the following phases: **Prototyping**, **Presentational Development**, **Pedagogical Authoring and Deployment**.

2.4.1 Prototyping

Prototyping is the conceptual design phase, typically in a meeting between the teacher and the developer. In this phase the teacher defines the educational goals and attempts to conceptually define the virtual apparatus that s/he will need. Unlike the real lab, where experiment design is confined to what is possible using real apparatus, our VAF approach enables teachers to envision unreal, that is un-physical, apparatus. For example, In the case of our Faraday's law adaptive tutorial the teacher's wanted the students to have a better understanding of how magnetic flux through a rotating coil changes as the coil rotates in the field. In a real experiment design, demonstration of this phenomenon will usually be done by connecting the coil to a voltmeter, rotating the coil and measuring the voltage on the coil. By applying Faraday's law and graphing the results, students should conclude the behavior of the flux threading the coil. However, using the VAF design approach, we simply created a 3d model that *showed* the flux through the coil thus enabling direct investigation of the phenomenon by the students [see Figure 2]. Clearly in reality one cannot "see" the magnetic field lines. However we harnessed the abstraction and simplifications that virtual simulations offer to escape traditional educational paradigms and were able offer new and exciting ways to demonstrate phenomena that were more concrete and so, easier to understand.

When thinking about educational goals and how these can be achieved using discovery and investigation utilized by VA's, we have found that it is easier for teachers to envision VA's while discussing hypothetical capabilities. This is because most teachers we have worked with had little or no experience in designing eLearning content, and are typically unaware of the amazing possibilities that virtual environments and simulations can offer. We thus offered teachers to begin designing thoughts with "it would be cool if we could…" so they are removed from their physically constrained thought processes of designing traditional instructional material.

Within the process of prototyping lies the very important process of interface specification to the VA. Typically the teacher will define the VA in terms of what it does and how it is used. For example, in the prototyping sentences "it would be cool if we had a visualization of the magnetic field threading the coil, so the students could rotate the coil to see how the flux changes", and "in some questions I'll vary the angle and ask the students to maximize the flux in that angle" lies an API specification for a scriptable control (e.g. Slider) controlling the angle of the coil in the simulation, that the developer will need to implement. This control is scriptable in the sense that the teacher can author questions that set that control to different value.

2.4.2 Presentational Development

The next phase in the development of VA's based adaptive tutorials is dedicated to developing the VA. In our examples, we developed our VA in Adobe Flash using prefabricated simple controls (e.g. sliders, buttons, knobs, etc) and complex VA modules (analog meter, virtual oscilloscope etc.) that we previously developed, and that are stored in our library. During the development process we made sure our VA adhered to the API specified in the prototyping phase.

2.4.3 Pedagogical Authoring

After the VA was constructed and refined by repetitive iterations between the developer and the teacher, the teacher is ready to author the VA into an adaptive activity. In the AeLP authoring environment, VA's are imported and scripted by the teacher. The content's pedagogical and presentational quality is strictly a function of the teacher's ability to create good learning experiences.

2.4.4 Deployment

after the learning activity is ready it is deployed and access by the students. The AeLP runtime environment is used to run the adaptive tutorials.

Our experience showed that the development process is indeed rapid where the key factor was in fact the teachers' understanding of the capabilities the AeLP offers. Once teachers could conceptually design virtual experiments with adaptive tutorials in mind (i.e. with API specification that will meet their scripting needs) the development cycle became a matter of about one week's work per adaptive tutorial. A proper evaluation of the technology is scheduled for 2007 and will be discussed in the Future Work section of this paper.

3 Developing Adaptive Tutorials Using the AeLP

A Core requirement when prototyping the AeLP for adoption by the School of Physics was offering relevant remediation and feedback based on student's interaction with the virtual experiments. This requirement naturally led us towards adaptive eLearning. Before we will discuss what adaptive tutorials are, and how they are built we will distinguish several modes of adaptivity which we will define.

3.1 Modes of Adaptivity

Adaptive eLearning is usually defined as eLearning activities where the Learning Objects are sequenced dynamically based on the system's model of student's knowledge level [9].

In our project, we define 2 types of adaptivity: **Adaptive Feedback** and **Adaptive Sequencing**.

3.1.1 Adaptive Feedback

Adaptive feedback is trying to offer remediation that is adapted to both the students' learning process and the VA's state. Feedback can be distinguished as follows:

- Per Question Feedback – where each question has right/wrong feedback.
- Per Attempt Feedback – where there is a different, typically progressively guiding, feedback tailored for each wrong attempt.
- Per State Feedback – where there is different feedback, for different Virtual Apparatus states.
- Stateful Feedback – this level of feedback is where the system offers more then just text as remediation, it actually offer steps towards the solution. This is analogous to a case in the real lab where a teacher spots that a particular student repeatedly fails to perform some task on the apparatus, for example manipulating two controls to achieve a desired state, and offers help in the form of fixing one control to the right value with some explanation. This type of active feedback involves helping the student's correct their misconceptions and fill in the gaps in their understanding of concepts. The system is reacting to students specific mistakes and using these to improve their learning experience. The AeLP was designed to allow for Stateful Feedback. For more information see Future Work below.

3.1.2 Adaptive Sequencing

Adaptive Sequencing – this is the "Holy Grail" of ITS – how to decide what learning activity will best suit the student next. For that we need a proper student model. So the system could reason: "based on the interaction with this student, it seems that s/he lacks knowledge about K. There is an activity A that teaches K in the repository. We will now present A to the student". We will see how the AeLP can take us a long way towards Adaptive sequencing in a very straight forward manner.

3.2 Adaptive Tutorials Structural hierarchy

In the AeLP there is no representation for the concept of Learning Objects. The "Learning Object", as a useful concept is a subject of debate [3], and our web-based re-usable educational content does not seem to follow the notion of a movable, distinct object, typically a file, that some reusability frameworks implicitly assume [1]. Our treatment of learning experiences falls closer to the notion of *learning services*. The AeLP defines a conceptual hierarchy for treating educational content: an *Adaptive Tutorial* is a collection of *Activities.* Each *Activity* is a series of *Questions* that are attached to a particular *Virtual Apparatus*. *Questions* typically contain some text, and define correct and erroneous *States* on the *VA* and attach *Conditional Feedback* to those states. *States* are defined by conjunctions and disjunctions of *conditions*, where *Conditions* are defined as triples of [*targetName*, *operator*, *value*]. For example a condition might be:

VA.angleControl.value = 0

Where the targetName is "*VA.angleControl.value*", the operator is '=' and the value is '0'.

The Adaptive Feedback Engine (AFE) module manages the display of the correct feedback to match the student's progression through the activity. In the heart of the AFE is a dynamic state matching engine that compares the state the student brought the VA to, and the list of error traps states defined for this question. The AeLP tutorial authoring process is simply defining states on the VA and attaching feedback to them. The possible targetName's that are available to the author (and the AFE) are a function of the API the VA exposed. There is an implicit assumption hidden here that all the conditions that are relevant for adaptive feedback stem from the state of the VA in any given moment, as in Constraint Based Modeling [17]. This assumption means that adaptation to the student's learning process can be achieved by examining solely the VA. This assumption is restrictive, because factors external to the apparatus, such as time to complete a question, navigational behavior, and of course past performance and accumulated knowledge should all be considered as well when offering adapted remediation. We discover that VAF approach can be easily extended so that properties external to the VA may be queried by the AFE, to base adaptive feedback upon. Such extensions can be achieved for example if we build functional modules within the platform that expose API that we can query. For example:

Platform.userInputPanel.inputText = "some text"

Or

Platform.attemptNumner = 3

will query the platform's Object Model for the targetName's of '*attemptNumber*' and '*userInputPanel-.inputText'* respectively [Figure 3]. This is possible because some aspects of the platform itself were constructed in such a modular way, that they adhere to the Virtual Apparatus API specification. This offers the extensibility of developing tailored platform's sub-features for different needs. For example we are currently working on a *userInputPanel* that will implement regular expression testing on input. In such a way, we could specify conditional feedback on user free input as in this following example:

Platform.userInputPanel.inputText isLike "some regular expression"

Furthermore we have developed a dedicated unit converter for Physics, which can parse such statements as:

Platform.userInputPanel.inputValueUnit = 70[meters]

and will give correct result if, for example, the student entered 0.07[kilometers].

We thus see how the Constraint Base Modeling approach, of authoring tutorials by defining states on VA's and attaching feedback to them, can be easily extended to include properties external to the VA, without loosing the simplicity and straight forwardness that Object Model [targetName, operator, value] specification offer.

3.3 Towards Adaptive Sequencing

A recent but very important development we have started researching is allowing for the current tutorial history to be a queryable Object Model by itself, adhering to the VA API specification. This means we can query such targetName's as:

Activity2.question1.selectedChoice = 3.

Or

Activity1.question3.correct = true

By allowing the History Object Model to be queried, we can effectively condition questions' sequence on student progression, as in the Model Tracing paradigm for developing ITS's [17]. This Object Model approach towards adaptive sequencing is novel, since it is possible to rapidly develop adaptive activities without explicit student modeling.

In this way we can leverage our powerful scriptable framework technology as a first step towards achieving the ultimate goal of adaptive student modeling. This work will be further discussed in the Future Work Section.

3.4 Reusability

Adaptive tutorials are kept in the system as scripts. Those scripts contain all the knowledge to drive an adaptive tutorial by the AFE. Tutorial files contain the pedagogical content (texts, questions, answers, feedbacks etc.) of the activity, but not the presentations, that are referenced by them and are loaded dynamically. Reusability is achieved by the ability to use the VA in different contexts, and develop different adaptive tutorials, or question, based on the same presentation. Furthermore, whole, or partial activities can be reused by dynamically, or statically referencing them in different tutorials. Dynamic referencing is the ability of the system to conclude that a certain activity should suit an individual student at a particular time, we also call this process Adaptive Sequencing. Static referencing is done during authoring of and Adaptive Activity, where the author decides to reuse an existing module.

4 Deployment at the School of Physics

During 2006 we developed 4 adaptive tutorials, built on 10 VA's, to match the syllabus requirements of first year physics students in the subject fields of Faraday's law and Light-wave diffraction. The two adaptive tutorials that were developed for Faraday's law, were deployed as pre-work and post-work multimedia components accompanying the related exploratorial in the first year physics lab. The tutorials were authored by 2 academics from the schools of Physics and Computer Science and were used by over 300 students during the year. We ran the AeLP in both semesters in pilot mode, and added a questionnaire at the end of each activity collecting useful statistics about users' expectations, satisfaction and opinions. Statistical analyses of the data are planned and are beyond the scope of this paper, but it is worth mentioning that our pilot resulted in high levels of interest and enthusiasm from both the students and academics in the School of Physics, together with useful feedback.

During the weeks when the subject matter was learned, students were linked to our platform by embedding a URL-link in the LMS (WebCT) page of their course. The interactions between the students and the VA were progressively sent to the server and recorded into our database. We currently have more than 6000 interactions; each includes a snapshot view of the state the students brought the VA into, on each attempt to answer a question.

While the adaptive tutorial was running, we run some manual queries on the database looking for students' repetitive mistakes. When we stumbled upon some unexpected cause of a recurring student error, we were able to dynamically change the adaptive tutorial and offer specific feedback to this particular error in a matter of several minutes. The power of a centralized student interaction online analysis and processing (OLAP) unit is evident, and is one goal of our research.

5 Future Work

We strive to create an environment that is as adaptive as a real teacher in terms of both feedback and order of information presentation, but also provides the benefits to the students of self-pacing, interactivity, remote access, and the ability to visualize abstract concepts. For the teacher the benefits include the ability track a whole group of students in terms of their learning progress and to quickly and easily update their lesson content accordingly. Many of these goals have already been met. Future work on the AeLP will focus both on its implementation side and its theoretical basis, particularly the issue of student modeling and adaptivity.

Implementation

- Extending the AeLP using VAF beyond physics. We already started prototyping a VA that will be embedded in a computer science course and we will explore its adaptation in other domains.

- User Modeling – one task for 2007 is developing the student model service of the AeLP.

- Adaptive sequencing remains the goal of our research and we will continue to investigate how our architecture, combined with the user modeling technology we are developing can be harnessed towards meeting that goal.

- Online Analysis and Processing – we are interested in online data mining of the interaction data from the concurrent multiple students so inferences such as recurring unexpected student errors could be noticed and communicate to the teacher.

- Collaboration engine – we will examine how we can allow students to collaborate work on a VA and how our system might monitor this collaboration with the goal of inferring interesting conclusions.

- Stateful feedback – we will implement the idea of Stateful feedback, were a remediation feedback and also embed an “apply” state, that is setting the VA to a particular state.

Theoretical

- Evaluation of pedagogical soundness - we will be carrying evaluation experiment to validate (or disprove) our hypothesis regarding educational benefits from rich interactive multimedia eLearning experiences.

- Evaluation of rapid prototyping – we will provide better metrics to study how content development using the AeLP measures against competing architectures

- Investigation of representations for student modeling generalizing constraint based and model tracing paradigms.

6 Conclusions

This paper outlined the AeLP - an ongoing research and development effort at the University of New South Wales aimed at developing an industry strength platform for development and deployment of multiple adaptive tutorials. We are not interested in the creation of one domain specific expert tutor that will teach a particular subject, but rather want to empower teachers with a rich, highly visual set of tools that will enable the authoring of state of the art eLearning experiences based on custom built Virtual Apparatus.

We used Virtual Apparatus Framework as a paradigm for developing learning activities. We found that VAF can reduce development time, promote learning content reusability and improve ITS adaptation by educational institutions.

Although we focused on VAF in the context of physics, we argue that cross disciplinary extensibility can be achieved by careful design of VA for other subject matters provided a pedagogical approach is employed that emphasizes interactivity. We outlined the content development process of designing and prototyping learning activities using the AeLP; we also showed how VAF allows rapid creation of adaptive feedback tutorials, and how we intend to continue towards adaptive sequencing.

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