



Web Technologies for Interactive Graphical e-Learning Tools in Engineering Education

Alexander Grigorov^{1,2}, Anton Angelov³, Ekaterina Detcheva², Petar Sabev Varbanov*⁴

¹Faculty of Mathematics and Informatics, St. Kl. Ohridski University of Sofia, 125 Tzarigradsko shosse, bl. 2, 1113 Sofia, Bulgaria

²Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Acad. G. Bonchev str., bl. 8, 1113 Sofia, Bulgaria

³CMC Bulgaria Ltd., Acad. G. Bonchev str., bl. 9, 1113 Sofia, Bulgaria

⁴Centre for Process Integration and Intensification – CPI², Research Institute of Chemical and Process Engineering, Faculty of Information Technology, University of Pannonia, Egyetem u. 10, H-8200 Veszprém, Hungary
varbanov@cpi.uni-pannon.hu

E-learning has grown in importance and popularity recently. Yet, it rarely goes beyond the mere publication of lecture notes and upload of course projects by students. There are new developments allowing live lectures over the Internet and new e-teaching initiatives such as “Coursera” have been launched with the participation of leading universities. The current article analyses the critical features needed to maximise the benefit from this type of education and the software tools offering some of these features. It suggests ways for possible further developments based on the lessons learned.

1. Introduction

E-learning is one of the technologies already coming of age, having developed vigorously for the last two decades (Clark and Mayer, 2011). Several leading technologies mainly oriented toward organisation and automation of the education process have emerged – e.g. Moodle (Moodle, 2012) or the HubZero system provided by Purdue University (HubZero, 2012) and others for knowledge management (DSpace, 2012). Recently, several leading US universities started offering online courses via a unified platform named Coursera (Coursera, 2012). Each course is structured as a set of lecture videos combined with quiz questions. Interactivity is mentioned in their publicity materials, but it seems that it is still a work in progress to really offer interactive exercises.

Engineering education presents a number of challenges. A major issue is the development of adequate tools and for interactive e-learning. Such tools should allow students to perform computational and algorithmic exercises from home while interacting with a server at a remote location – e.g. at a university. The desired capabilities of such tools include construction of mathematical models including both equations and algorithms; construction of plots/graphs as well as sketches and possibility to manipulate them; saving partial work or final results to the university server; submission of completed work to lecturers and supervisors for evaluation and advise; evaluation of the work.

This paper provides an overview of existing open source and commercial e-learning software tools offering some of the desired features, with the intent of deriving targets for building interactive e-learning tools. A critical analysis provided of the needs for further research and software development to enable the most efficient and ergonomic implementation of the desired learning capabilities.

2. Feature requirements

2.1 The teaching context: Integrated knowledge management life cycle

Integrating research and training into a coherent life cycle (Figure 1) would allow achieving and maintaining high quality of training and research. Under such a framework, starting from an initial set of curricula, the training steps are followed by research-training, feedback from knowledge users and research. The next stage – the curricula update activity, closes the cycle providing the feedback for achieving high quality of the training as well as accelerated evolution of the knowledge base.

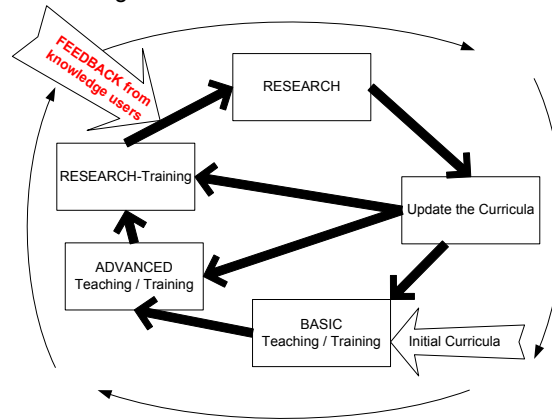


Figure 1: Integrated knowledge management life cycle

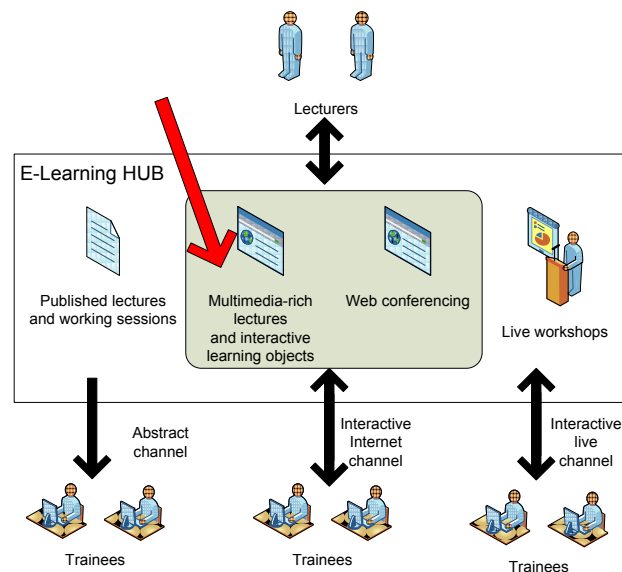


Figure 2: Knowledge transfer channels

While the integrated lifecycle provides the necessary condition for high-quality knowledge development and management, the sufficient condition is to allow for sufficiently intensive flow of knowledge transfer during training. A key element is gathering feedback from the knowledge users, which should ensure high relevance and up-to-date quality of the knowledge base. Knowledge can be viewed as being transferred by several channels for perceiving information. The following channels can be distinguished as illustrated in Figure 2:

- Well structured lectures and written exercises use an abstract channel of information transfer.
- Multimedia-enabled presentations, including animations and/or video clips involve more perception ways, including seeing the gestures and sketches shown by the lecturer.
- Interactive working sessions (learning objects) in addition to written exercises. These would allow involving additional associations and senses in the training process further improving the quality and speed of learning, based on the principle of learning by doing.

The current work focuses on the features allowing the implementation of interactive working sessions and exercises.

2.2 Connectivity

In many cases it is either impossible or too costly for students and trainees to travel for eye-to-eye classes. Therefore, users should be able to connect from anywhere with Internet connection using a web browser or a custom thin client. Web-browser-based content delivery has the advantage to allow access via a standard interface, which is learned from early age and is currently pervasive.

2.3 The need for interactivity

Interaction of the student with the problem and the lecturer is essential in achieving comprehensive understanding. In classical education forms this is achieved by providing live working sessions and laboratory exercises. In the context of distance learning there are some attempts to providing interactive learning experience. A common feature of these approaches is that they, in fact, cater for very basic forms of learning, mostly concerned with operator training – acquiring skills or intuition, rather than core knowledge. Examples include:

- Simulation of a process using a back-end model in response to user inputs (Guzman et al., 2008)
- Game-based training for decision making in engineering (Chen and Lin, 2010)

2.4 Interactive knowledge objects

From the previous analysis it has become clear that the modelling and training environment to be provided has to be object-oriented and object-based. In order to cater for the needs of engineering students, who should learn to also create models, as opposed to only using them, the environment should be able to handle creation and management of interactive knowledge objects. They can be:

- Tables with data. Optionally the tables may offer spreadsheet functionality for computing derived/dependent data/variables. The data to handle could be both text and numeric.
- System/component models. These should be objects describing models of real-life or abstract objects. They should have both equation-based model description and visualisation parts. Examples of engineering objects to model are: gas turbine, boiler, clock. Example abstract concepts include: triangle, polygon, business process (from BPMN translated to set of equations). The models can be based on the open Modelica language (Modelica, 2012), or UML (OMG, 2012). Another modelling language can be also used/developed. However, the features offered by Modelica are essential for a successful engineering implementation and should be reused. The language specification defines objects containing variables, equations, and also algorithms. This is a very powerful combination, since certain model parts can be rather algorithmic, although possible to describe using equations.
- Custom interactive plots and customised diagrams. These are essential elements of any engineering activity and students should also learn how to exploit them efficiently. Examples of plots include Composite Curves and Grand Composite Curves (Klemeš et al., 2010). Customised diagram examples include heat cascades, resource cascades or algorithm visualisation (Klemeš et al., 2010).
- The environment should offer the possibility to for the components to connect and interact. The nature of the interactions can be parametric (via values of the connecting variables) or event-based.

3. Desktop applications providing desired features

A good example of an interactive teaching desktop application comes from the area of process control (Guzman et al., 2008), termed Interactive Learning Modules (ILM). This source presents 3 ILMs for use by students in learning PID control. The tools are aimed to partially replace laboratory pilot plants and developing operation skills before using the actual pilot plants, saving costs and improving the safety of the education process. The tools come as executable desktop applications compiled for PC, Mac and

Linux platforms (ILM, 2005). The main advantage of the tools is that they do offer interactive experience in learning how process control works. However, they are limited to using predefined models and do not offer the capability of model implementation and testing,

Martin-Villalba et al. (2012) offer another variation of an interactive teaching tool for process control termed a "Virtual Lab". This is developed based on Modelica (Modelica, 2012) and its commercial implementation Dymola (Dymola, 2012). The Modelica-based Virtual Lab offers similar functionality and interactive learning experience as the ILM. However, being based on Modelica, it allows more advanced manipulations via changing the process and controller models and obtaining a different behaviour to interact with. This is performed by re-compiling the model from Dymola.

A common limitation of both examples is that they are strictly focused on process dynamics and control. As a result, the implemented process models are inherently dynamic and implementation of algebraic models is only optional. This prevents the use of efficient algebraic solvers for process optimisation. Finally, a serious problem in the offered capabilities is the lack of scalability for remote use as defined in the goals of the current study.

There are also many software suites of varying complexity – including powerful process simulators Aspen Plus (AspenTech, 2009) and UniSim (Honeywell, 2010). They offer building of flowsheet models, but the models of their unit operations are closed and not accessible for manipulation or modification. Other dynamic process simulators as gPROMS (PSE, 2009) do allow custom model formulation and the generation of useful plots and graphs. These tools, however, are equation-centric and focused on formulating and solving systems of differential-algebraic equations, while the features of problem and algorithmic visualisation are largely missing. The matrix-based tools for mathematical modelling – e.g. Matlab (MathWorks, 2009), Scilab (Scilab, 2009), are also very powerful and have been used in engineering classrooms for years. They offer extensive model building and interaction capabilities, but fall short of providing remote connectivity and convenient document-like interfaces.

From the desktop applications approaching the defined requirements, Matcad stands out as providing the closest match. It offers a sheet-like interface for defining sets of equations and also has algorithms for numerical and symbolic processing of the models. Its only shortcomings are the lack of internet connectivity and of the capability of creating customised diagrams.

4. Web applications providing desired features

4.1 Online interactive document collaboration

The Internet giant Google offers a very useful collaboration tool, called Google Docs (Google Inc, 2012). This is only one of the online services offered by Google. It allows creating various kinds of standard documents – text, spreadsheet, drawing, presentations. From the viewpoint of interactions, a document can be simultaneously viewed and edited by several users, seeing and making all changes in real time. Combined with an audio conversation this can be quite good tool for discussions. An obvious problem for using this service for online education is that this kind of document sharing is limited to very simple possible models connected to static data connections and documentation.

4.2 BigBlueButton: remote lectures and live interactions

BigBlueButton is an open-source web conferencing system (BigBlueButton, 2012). It offers an easy to install and use software package, which installs as a server. The provided functionality includes live web conferences – including both audio and video, recording functionality and an online white board. The white board functionality is quite basic allowing to draw shapes and make sketches. The system also allows desktop sharing, which can be used for illustration of modelling and computation procedures. This, however, stops short of providing the learner an interactive modelling and educational experience beyond the interaction with the instructor.

4.3 MOSAIC Modeling Project: Internet-based modelling and documentation

A team from the Berlin University of Technology has developed and offers a web-based tool for dynamic modelling of industrial processes – e.g. distillation, reactors, named MOSAIC (MOSAIC, 2012). The tool offers a blend of model implementation as well as documentation, which brings the resulting model closer to the style in which a final report or research article looks like. The environment is based on a modularised modelling language, deriving a subset of LaTeX. MOSAIC also

allows interaction among different work groups. On an abstract level this system offers many of the features needed for the interactive completion of exercises by students – especially important is the provision for combination of mathematical model and documentation. From the viewpoint of providing an interactive learning experience for engineering students, one missing feature is the ability to prepare custom interactive plots and customised diagrams – e.g. various kinds of resource cascades.

4.4 Interactive web classrooms

WizIQ (WizIQ, 2012). Is a web environment that enables synchronous distance learning using real-time virtual classrooms with multi-way audio, up to 6 live video streams, integrated chat, interactive whiteboards, application sharing, file transfer, breakout rooms. The whiteboards are claimed to allow interactive drawing, as well as entering and solving mathematical equations. When testing the demo the drawing was active but no equation solving features were available.

5. Emerging interactive web technologies

Rapid technological advances in web technologies have led to the introduction of the new markup language HTML5 (W3C, 2012). HTML5 enables innovative ways of interaction between users and between users and systems not possible before. Support by the leading web browsers is considerable and increasing with each new version. HTML5 in combination with CSS3 and jQuery provide the necessary tools to move e-learning environments from being static web-based copies of traditional learning materials to collaborative web applications that provide multimedia content that is interactive, responsive and dynamic (Jobe, 2011). The following list provides the major features of HTML5 and the new JavaScript APIs that can be used to create a collaborative e-learning environment (Jobe, 2011):

- Canvas – HTML5 implements a new canvas tag allowing for web applications to draw 2D graphics;
- HTML5 is natively user editable;
- JavaScript APIs and jQuery – jQuery is an open source, cross-browser JavaScript library that is used to simplify scripting of web pages;
- CSS3 – A new improved version of CSS (Cascading Style Sheets) that offers greater control and flexibility for creating modern designs;.
- Web Sockets and SSE (Server Sent Events);
- Cross Document Messaging;
- Geolocation - By using the new JavaScript Geolocation API, web applications can reveal a client's physical location as well as show where other users currently are. This process can only be done with the user's permission;
- WebGL – Is a standard for programming in 3D when using the web browser as a platform. WebGL is an interface between JavaScript and OpenGL, which allows for hardware accelerated 3D rendering using the HTML5 canvas tag;
- Web Workers – allows JavaScript code execution in parallel without affecting the user interface;
- Microdata – This feature in HTML5 allows semantically defined web pages;
- RDFa – RDFa is a W3C recommendation for embedding metadata into web documents;

6. Conclusions

From the presented overview and analyses it can be concluded that for offering high-quality distance learning, the process of knowledge transfer has to be considered within the context of an integrated knowledge management life cycle. It has to offer a number of critical features, related to providing remote connectivity, interactivity and enhanced understanding via human-readable interfaces, approaching the appearance of printed documents.

Many desktop and web-based tools offer partly most of the needed features and none of them offers all features. The common shortcoming of all tools available on the market is the lack of capability of defining and conveniently displaying interactive knowledge objects.

The above analysis reveals several directions for future development in the area of tools for supporting interactive exercises for efficient e-learning. The first direction should be a systematic mapping of all needs such an application should offer, accounting for the fact that the fundamentals of the required

technology are available as elements in already existing products. Therefore, the analysis should provide a pathway of reusing these technologies and ideas combined into a single platform.

It is further needed to formulate a modelling language based on the Modelica specification and combine it with algorithms for simulating and optimising algebraic and differential systems of equations. The final critical action will be to develop an efficient implementation of the modelling language, building a web-based tool with the appropriate interactive features and human readable interface.

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