Integrated Component Web-Based Interactive Learning Systems for Engineering

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Abstract—Dynamic web-based learning tools are indispensable in modern teaching, especially considering their capability for interaction on demand as a means of stimulating and engaging students. The experience on which the results reported here are based has grown out of progressive testing of different approaches for publishing technical sketches and mathematical notations from the field of electromagnetics on the web, starting in 1997 with simple static web pages of solved examples. The encouraging results from using and evaluating this educational material and the needs expressed by students for learning from more dynamic and interactive web learning materials that offer the possibility of changing parameters in online calculations motivated a search for new approaches to publishing interactive learning materials on the web. Integration of already developed components for building animations, presenting mathematical equations, and performing online computations with browser scripting led to development of a learning environment where animations are synchronized with corresponding derivations of equations and supported by dynamic, parametric-driven calculations and visualizations that can be integrated with sound and video. The system supports tests and examinations in which the answers are provided as mathematical notations. The use of Mathematical Markup Language (MathML) permits equations in the learning materials to be copied and pasted into most of the popular mathematical software tools for algebraic manipulation or numerical computation. Examples demonstrate how the system can be used with a course on electromagnetics, although the basic approach is applicable in other fields of engineering and natural science.

Index Terms—Interactive technical sketches, mathematical notations, network traffic modeling, online calculations/visualizations, system access evaluation, web-based education.

I. INTRODUCTION

MODERN web-based technologies [1]–[4] can function as a bridge between difficult educational programs on one side and students who need considerable motivation on the other. These technologies are welcome additions both to the classic educational process and for autonomous asynchronous study. They can incorporate dynamic displays, interactivity, online calculations, audio, and video. All these attributes can have a stimulating effect on students [4], [5]. At the same time, thoughtfully prepared content can represent a stepping-stone for further research by students and for their study of supplementary literature.

In engineering, a basic element of explanation is a good technical sketch. In addition, technical writings often include equations, special notations, and graphs. Today, web-based technologies efficiently support these elements. In comparison with traditional printed books, web-based technologies offer the advantage of allowing individual parts of technical sketches to appear gradually on the screen through animation, synchronized with, for example, corresponding steps in the derivation of equations. Furthermore, navigational and dynamic elements can provide interactivity. For example, mathematical tools with web support can be integrated into the web-based learning environment so that students can see the results of changing the values of parameters in calculations and graphs.

Using such web-based educational environments, students can gain better insight into the usually demanding and often difficult-to-imagine role and meaning of theory in a particular discipline. Moreover, students can access a vast spectrum of practical examples that preview even more complex structural problems with which they will have to cope during further study, engineering practice, and research. The web-based system also can support pre-laboratory learning. Offering guided step-by-step instructions through assignments enables students to learn the concept of problem solving so that later they can come to appropriate solutions by themselves.

In previous work, authors have developed and implemented proprietary classical [6]–[11] or web-based [12]–[17] applications tightly related to a specific course. Work by Fisher and Michielsens, for example, incorporates some of the engineering learning content elements in a web-based simulation environment built with the Mathematica gateway [15]. In this system, the Mathematica kernel is accessed through a web-based graphical user interface by using scripts based on the Common Gateway Interface (CGI). This system provides interactive computational and visualization capabilities, but does not address the presentation of other necessary elements, such as interactive equations, technical sketches, and animations. Also, the users of the system need some knowledge of Mathematica.

Such applications are compelling individually, but can be very hard or even impossible to employ in other courses. Often, the environments include only limited capabilities for visualization or presentation of equations. Usually, modifications and improvements require further development of the software. To reduce entanglements with specific course material, contemporary web-based learning environments can rely on contemporary standard-based or widely available commercial components, which now support essentially all
necessary engineering learning content elements. Specifically, such components support integration of technical sketches, animations, mathematical equations, graphs, sound and video, dynamic displays, interactivity, and server side computation and visualization.

The basis of the results reported in this paper is experience in testing different approaches for publishing technical sketches and mathematical notations from the field of electromagnetics on the web that began in 1997, with publishing of solved exercises using static Hypertext Markup Language (HTML) and Graphics Interchange Format (GIF) images. Continuing efforts have produced a digital library that includes more than 1000 solved exercises and is growing through the addition of 100–150 additional exercises per year [18]. Since the end of 1999, when the website was restructured into a portal, the Acrobat Portable Document Format (PDF) has been used for publishing the content. Section II discusses both the HTML + GIF image approach and the Acrobat PDF approach with their advantages and disadvantages.

In 2003, an evaluation of this website was made in two different ways [5]. First, a survey was carried out among students to find out their opinions. Second, the web server log files and the network traffic were analyzed. The analysis revealed a great and constantly increasing interest for this educational material among Slovenian students. A surprisingly high percentage of students claimed that they use the system very frequently to study for an exam, and most of them indicated that they would like to use a similar system in other courses. In addition, students indicated that they would like to see the exercises solved in a more detailed and structured way in dynamic and interactive web material provided by teachers and would like to investigate phenomena themselves by changing parameters in online calculations.

These student interests motivated a search for new approaches to publishing the material and to extending the educational process by using animation synchronized with corresponding equations, sound, and other multimedia elements. Lately, many software components that offer partial support for incorporating these educational content elements in engineering study material have been developed and have become popular and frequently used. Thus, development of new approaches and new plug-ins to present animations, equations, visualizations, and tests on the web was neither necessary nor reasonable. Consequently, the system described here relies as much as possible on these widely utilized components.

The interactive web-based examples presented in this paper provide supplementary pre-laboratory background for the laboratory experiments of the course Fundamentals of Electromagnetics. The subjects covered by this course include electric fields, electrostatic forces, movement of particles in electric fields, breakdown, magnetic fields, magnetic forces (rotation), induction, electrical circuits, Kirchhoff’s laws in circuits, Thévenin’s theorem, ac circuits, and power.

After describing and comparing the approaches used for web presentation of mathematical notation, Section II demonstrates the advantages of equation reusability with MathML and the possibility of using equations as answers in web-based tests. Section III introduces and reviews the tools for preparing technical sketches and interactive animations and describes an approach for integrating animations with the corresponding derivation of equations. In Section IV, mathematical packages providing web-based access to the server-side kernel of a mathematical package are described, and taxonomy that aids comparison is provided. In Section V, the system design concept is presented, and the integration of the various components is demonstrated by reviewing examples from the course on electromagnetics. Section VI discusses experiences in using the web-based tools as a supplement to traditional teaching methods in an introductory course on electromagnetics.

II. Mathematical Notations on the Web

This section describes three basic concepts for publishing mathematical notations on the web—their advantages and drawbacks. The first two are described only briefly because they provide no interactivity and reusability and, consequently, are of little interest in dynamic, web-based environments. More extensive description of them appears in [19]. A comparison of the three approaches is summarized in Table I.

<table>
<thead>
<tr>
<th>Table I</th>
<th>Comparison of Concepts for Publishing Mathematical Notations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HTML + GIF</td>
</tr>
<tr>
<td>Simple content building</td>
<td>No</td>
</tr>
<tr>
<td>Font size problems</td>
<td>Yes</td>
</tr>
<tr>
<td>Printing quality</td>
<td>Low</td>
</tr>
<tr>
<td>Interactivity</td>
<td>Partial*</td>
</tr>
<tr>
<td>Combination with other media</td>
<td>Yes</td>
</tr>
<tr>
<td>Reusability</td>
<td>No</td>
</tr>
<tr>
<td>Notations as answer to questions</td>
<td>No</td>
</tr>
</tbody>
</table>

* Documents can be exported directly from some word processors; no interactivity can be achieved with this approach, however.

| **A. HTML + GIF** |

The earliest, simplest and most naive approach to publishing mathematical notations on the web is by using native HTML capabilities to combine text and symbol fonts with tables and black and white GIF pictures for mathematical notations and technical sketches. There are several drawbacks when using this approach in practice. 1) *Equations do not display the same on all computers and in all browsers.* The size of the notations depends on the resolution of the screen and is, therefore, bigger when the resolution is low and the other way around. Moreover, adjusting the text size in the browser settings cannot change the display size. Both of these problems lead to inequality of size in the symbols used in notations and those used in the text. The resulting appearance of the document is displeasing. 2) *Equations and pictures do not print in suitable size.* They may print either too small or too large. If they print too large, the low-resolution GIF images, usually meant for display on a screen, appear jagged. 3) *Complex documents can generate hundreds of GIF files.* 4) *The published material suffers the lack of interactivity.* The content of notations cannot be changed through user interaction, an important disadvantage in modern web-based learning material. 5) *The equations cannot be reused directly for further computations by the students.*
The main advantage of this approach is its simplicity in requiring no additional plug-ins or special software to view the content in a browser.

B. Acrobat PDF

Simplicity in document creation and publishing with the Acrobat PDF format has led to its widespread use among those who publish technical documentation, research papers, and educational material on the web. A PDF file, created simply by printing to a file, is a precise copy of the original document, which can be prepared in Microsoft Word, TEX, Mathematica, MathCad, etc. The author, therefore, has total control over the formatting. This approach ensures very accurate printing of the text and notations in the content published on the web. However, the PDF format requires users to install a special plug-in to display the documents in a browser. Unfortunately, this approach provides little interactivity beyond simple linking and provides no possibility of reusing published mathematical notations for further calculation, plotting, or simulation.

C. Mathematical Markup Language

MathML is an XML language that defines the structure of mathematical expressions so that they can be displayed, manipulated, and shared over the web [20], [21]. This language nowadays represents a standardized link between different applications that provide mathematical content and programs/browsers used to present it. A carefully encoded MathML expression can be evaluated in a computer algebra system, rendered in a web browser, edited in an equation processor, printed, or even articulated by a speech synthesizer. Most Mathematical software vendors have already implemented MathML support, thus MathML is becoming the lingua franca of scientific publication on the web. However, the presentation of MathML is not natively supported in all web browsers (Table II, [22]), although Design Science MathPlayer—a free MathML rendering component—enables Internet Explorer to display MathML.

Mathematical notations can be encoded as MathML separately and then inserted into the HTML-based educational material, or they can be composed using WYSIWYG editors, such as MathType or webEQ [23], [24], a comprehensive Java toolkit for building web pages that include dynamic math. A very popular way to produce mathematical notations in a web-based education system is by using server side tools for mathematical computations, discussed later in Section IV, that can directly produce MathML output for displaying mathematical content.

The introduction of MathML eliminates most of the problems previously described in incorporating mathematical notations in learning materials for engineering students. For this reason, and the important pedagogical advantages discussed below, MathML presentation of equations in contemporary web-based education material offers compelling advantages to content developers and was chosen for the work here.

1) Reusability of Mathematical Notations: Mathematical notations written in MathML can be used for further mathematical calculation, graphing, searching, and analysis. Major computer algebra systems, such as Mathematica, Maple, and MathCad, support copy-and-paste of a MathML expression from web-based learning material into their documents (Fig. 1).

The possibility of copying and modifying equations and parameters can encourage students to make further calculations by themselves and thus investigate a problem more seriously.

2) Questions Answered With Mathematical Expressions: In the past, automated examination and self-testing of students’ knowledge in the domain of mathematical notations was hard to perform. Students usually were offered a choice of several answers prepared by the authors in advance. Using MathML as a protocol for communication between a web client and an application for evaluating the input, students can answer questions by writing mathematical expressions. Integration of graphical equation editor applets, such as the webEQ Input Control [23], into an educational web page with questions can enable the examinee simply to write the answer to a given problem in a WYSIWYG manner (see Fig. 2). In the background, the answers are compiled in MathML format; after clicking the “submit” button, they are sent for evaluation in a way similar to that in which values are collected by other HTML form elements. The processing can be done either with JavaScript code embedded in the same web page [25] or by an application at the web server side.

Students are not required to enter their results in simplified format. For example, they can respond with \((r^2 - 4)\) or with \((r - 2)(r + 2)\)—both are treated as the same result. To verify and evaluate correctly a given expression on the client side with JavaScript, an Evaluation Control applet [23] can be added to the document. This control utilizes sophisticated mathematical algorithms to compare MathML expressions and determines when two expressions are equivalent. The other possibility for verification of answers written in MathML is to use server-side applications to process the MathML, simplify the expression, and perform the assessment.

III. ANIMATIONS

The importance of technical sketches as an element in educational material for engineers was discussed in the Introduction. In contrast to the black and white static technical sketches usually used in books and journals, modern web-based technologies offer the possibility of using colorful and dynamic two- and three-dimensional (2-D and 3-D) sketches and animations. The main advantage of the latter from a pedagogical perspective is their ability for providing user interaction. They can be triggered by time or by specific events, such as a mouse click on the “Next” button. This capability enables gradual presentation of information to learners so that new items can appear individually, step-by-step. Each step can be synchronized with corresponding equations, which are usually derived from previous
equations. Explanatory comments can be added with additional text or voice. Beyond explaining derivations, animations with integrated speech or video clips also can be an effective means of explaining some concepts and phenomena.

A complete and widely used package for animation is Macromedia Flash, which provides powerful features for animation, multimedia, and application development, features that allow designers and developers to create rich e-learning courses [26], [27]. An example of its use for preparing 2-D animations and visualization of phenomena is shown in Fig. 3.

Developers of e-learning content interested in describing functions in space from the fields of engineering and natural science might wish to prepare 3-D animations carried out by using MindAvenue Axel [28]. Axel Educator’s Program offers excellent capabilities for modeling, animating, texturing, lighting, previewing, integrating, and publishing interactive educational contents to the web without the need for programming. Although this tool makes possible composition of almost any content imaginable, preparation requires considerable time and effort.

A. JavaScript as a Link Between Interactive Elements

The possibility of moving through animations step-by-step with navigational elements integrated into a web page was noted earlier. Alternatively, the animation steps can serve as triggers to move through successive corresponding steps in the derivation of an equation, to perform online calculation with particular values, to draw graphs with selected parameters, to start sound clips with explanations, or to run video clips.

In practice, the integration of these technologies is accomplished by client-side scripting, e.g., JavaScript. For example, to achieve the step-by-step derivation of equations, the MathML code of all levels of derived equations is prepared in advance and stored into several JavaScript variables. When an appropriate event takes place (mouse click on a “Next” button, animation triggered event, etc.), the content of equations is replaced by the
Fig. 3. Three steps of solving a problem in electromagnetics, presented using flash animation dynamically synchronized with corresponding equations written in MathML.
next-level JavaScript variable, resulting in a new equation presented to the user [see Fig. 3].

To control the web-based content by sensible elements within animations, suitable scripting must be integrated during their compilation. Macromedia Flash and MindAvenue Axel both support the usage of JavaScript. For example, Fig. 4 shows how ActionScripting is used for triggering browser scripts in Flash. These scripts dynamically control MathML content that is synchronously previewed in MathPlayer. With this approach, MathPlayer can be employed for dynamic presentations of notations in coordination with animations, an approach that represents an excellent opportunity for structured presentation of engineering problem solutions.

IV. ONLINE CALCULATIONS AND VISUALIZATIONS

The benefits of educational material that contains animations synchronized with corresponding derivation of equations and other multimedia elements were noted in earlier work [29]. This section focuses on an approach that provides on-line visualization of relations governing electromagnetic fields in space and in time rather than derivation of equations. According to the analysis mentioned earlier [5], students not only want to learn from examples prepared in advance, but also want to be able to change the parameters in calculations, graphs, and animations. This ability allows them to find answers to their questions and to understand certain terms better.

Portability across operating systems, strong support for visualization, analytical and numerical computations, and presentation of equations with MathML can result from employing one of several powerful mathematical packages that have become widely available. Today, most of the companies that make mathematical packages for analytical and numerical arithmetic offer supplements that provide access to the mathematical kernel of the program through a web interface. These supplements allow building of examples that help students to carry out efficiently their own limited analyzes and more complex analyzes prepared in advance by tutors. Students do not need any special knowledge about the software tools for mathematical analysis or even knowledge about which mathematical tools are being used in the background of the educational system.

During the process of choosing a platform, the documentation for several mathematical systems that offer the capability of computation and visualization through a web interface was reviewed as follows:

- Wolfram Research webMathematica [30];
- The MathWorks Matlab webServer [31];
- Maplesoft mapleNet [32];
- Mathsoft Mathcad Application Server [33].

Wolfram Research webMathematica and The MathWorks Matlab webServer were installed and tested. In related work [35], an extensive review and comparison is conducted of all the systems listed. To summarize results from the review, taxonomy is given in Table III. In regard of its capabilities, ease of installation, effectiveness of integration with other components of the web-based education system, and experiences from the past, webMathematica was chosen as the mathematical package for driving the online calculations of the web-based educational system described here.
TABLE III

<table>
<thead>
<tr>
<th>Server platform</th>
<th>webMathematica</th>
<th>Matlab Webserver</th>
<th>mapleNet</th>
<th>Mathcad Appl. Server</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client Requirements</td>
<td>Windows, Unix/Linux</td>
<td>Windows, Unix/Linux</td>
<td>Windows, Linux, Macintosh</td>
<td>Windows</td>
</tr>
<tr>
<td>Symbolic Calculations</td>
<td>Yes</td>
<td>Yes(^a)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Numerical Calculations</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>MathML Support</td>
<td>Yes</td>
<td>Partial(^b)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Visualization</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3D Preview</td>
<td>LiveGraphics3D</td>
<td>JPG images</td>
<td>mapleNet applet</td>
<td>PNG images</td>
</tr>
</tbody>
</table>

\(^a\) no MathML support by default
\(^b\) by using Symbolic Math Toolbox
\(^c\) by using MathML Visualization tool [34]

**A. webMathematica**

Wolfram Research webMathematica adds interactive calculations and visualizations to a web-based educational site by integrating Mathematica with web server technology, such as the Apache web Server. This extension makes possible the construction, test, and deployment of specialized web services for computation and visualization, all powered by a large library of Mathematica commands on the server side.

The system is based on two standard Java technologies: Java Servlets and JavaServer Pages (JSP). Page code, similar to HTML, is enhanced by the addition of Mathematica commands. When a request is made for one of these pages the Mathematica commands are evaluated, and the computed result is placed in the page. This process is performed with the standard Java templating mechanism, JavaServer Pages, making use of special tags and the request/response standard followed by web servers. The input is usually entered through HTML forms, applets, JavaScript calls, or interactive animations (as shown in previous section) although data files or Mathematica Notebooks also can be sent to a webMathematica server for processing.

Output can be presented in many different formats—the most interesting for web-based education are HTML, MathML, images (2-D/3-D graphs), XML, and text, although the output can also be a Mathematica notebook, SVG, PostScript, or PDF.

An important part of this system is the kernel manager, which calls Mathematica in a robust, efficient, and secure manner. The manager maintains a pool of one or more Mathematica kernels, which can process several requests at a time. An overview of deploying webMathematica is shown in Fig. 5.

The aim of webMathematica and JSP technology is to reduce the amount of specialized knowledge required of those who use the site and to minimize the time needed for developing the
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Fig. 7. The system architecture.

Fig. 8. HTML code with JavaScript for integration of flash animation and webEQ viewer to achieve the step-by-step derivation of equations depicted in Fig. 3.

educational content. In practice, authors must know something about HTML and Mathematica although they need no extensive knowledge of Java. Basic knowledge of JavaScript is needed for performing integration with other educational elements. For example, integration of Flash and webMathematica is possible by using JavaScript. In this way, graphs can be presented as parts of animations, and interactive communication with animations can be redirected to server-side mathematical tools as parameters for computation and visualization.

Incorporation of the webMathematica LiveGraphics3D applet in the web-based educational material permits easy integration of webMathematica results into a web page. This applet displays Mathematica 3-D graphics and provides features, such as interactive rotation and resizing of elements. The applet works in a wide range of different Java-enabled browsers.

An example of visualization with webMathematica is given in Fig. 6, which shows the magnetic field of a current element with different strength/direction of the current as a parameter.

Through more detailed consideration of examples introduced earlier in this paper, the next section illustrates the integration of Mathematica into a learning environment with Flash animation, MathML (both for display and for user input of mathematical expressions), JavaScript, and visualizations (static and dynamic).

V. DESIGN CONCEPT AND IMPLEMENTATION

A. The Design Concept of the System

The central element of the system is the web server, used for delivering the web-based content. The web server natively delivers the contents as HTML, GIF, JPG, and Flash Animations. The JavaScripts are parts of the HTML documents. To perform online computation, webMathematica must be installed on the server. The architecture of the system is shown on Fig. 7. Providing other types of content requires installation of different features, i.e., installation of Windows Media Services for video streaming, etc.
The implementation described here uses the Windows 2000 Server. The system is integrated into E-CHO (e-learning system at the Faculty of Electrical Engineering, University of Ljubljana), a system that permits the authentication of users, the collection of statistics, network traffic measurement, support for video streaming, and use of e-learning study tools, such as forums, email correspondence with tutors, videoconferencing, etc.

B. Analysis of the Examples

This section shows source code for the examples shown in figures of previous sections and discusses its functionality. These examples can be found at [36].

Fig. 8 shows the structure of an HTML document that integrates a Flash object [see Fig. 8(b)] for animation and a webEQ Viewer Control applet [see Fig. 8(c)] for presentation of the dynamic derivation of equations. The integration is performed by using JavaScript [see Fig. 8(a)]. The successive steps of equations are stored as separate variables in MathML format and appear gradually in the viewer applet when triggered by an ActionScript from the Flash animation (see Fig. 4).

Fig. 9 reveals the Java Server Pages code of web material that includes visualizations, such as the one in Fig. 6. The static visualizations can be generated in advance by Mathematica and only displayed in the web course [see Fig. 9(b)] or can be calculated on-line at the server side by using the parameters entered by the user with a form [see Fig. 9(c)].

Fig. 10 shows the code of a questionnaire that allows entering a mathematical expression as an answer to a given problem, such as the one shown in Fig. 2. The questionnaire document is composed of a static image of a problem [see Fig. 10(b)], a question composed of text that includes MathML [see Fig. 10(c)], and a call of the webEQ Input Control applet [see Fig. 10(d)]. In this example, some of the possible answers are predicted and stored in JavaScript variables [see Fig. 10(a)], and JavaScript also evaluates the answer. However, authors ordinarily should take advantage of the more versatile and robust evaluation features of the Evaluation Control (see Section II-C2) or the server side mathematical tools (see Section IV) for verification of answers.

VI. USAGE EVALUATION

System usage statistics and student opinions have been collected during the seven years since 1997, when publishing web-based educational material for the field of electromagnetics commenced. At the start of the year 2003, however, a more detailed study began that used two different approaches: analysis of the web server log files and network traffic load characteristics, and a simultaneous survey among students.

A. Website Access Evaluation

The website access evaluation was conducted by analyzing the web server log files. The logs indicate which material the students review, how frequently students use the system, how the usage is distributed over the day, week, month or year, etc. The log analyzes give an opportunity to build models of system usage, which show exponentially distributed lesson intervals during which the data is being sent in bursts of nearly uniform, distributed length. The reader is referred to [38] for more detailed information about user access modeling.

The website evaluation was completed with webTrends Log Analyzer, which generates several predefined reports. The reports show the number of visits in certain periods, amount of transferred bytes, most/least frequently used pages, etc.

Access analysis for the year 2002 revealed 187,220 accesses during this period. The number of accesses in December 2002 increased 25% over December 2001, as shown in Fig. 11. The peak day of access was 10 June (2351). The monthly distribution of requests shows that interest increases during the exam periods in January, April, June, September, and December, while the lowest interest in the study material occurs during the summer holidays (July, beginning of August).

In the last three years, the number of users has remained steady, probably because almost all the first year students, for whom the material is intended, are using the material. Recently, the system has also been introduced to teachers of more advanced courses. They are expected to adopt this approach in the near future. Consequently, the number of users is going to increase.
B. Network Traffic Measurement

To understand the system load, ensure Quality of Service, and predict required network resources for the future, the network traffic is continuously being measured and analyzed [37] at the e-learning system that provides the described web-based study material.

Over time, the network traffic characteristics of the e-learning environment are changing for the following reasons: 1) as described in Section VI-A, both the number of users and their interest are continuously growing; 2) the majority of users study from their homes, where the low-bandwidth modem internet connections have recently been replaced with high-speed broadband technologies, such as cable or ADSL; 3) the study material has been enhanced with multimedia elements, particularly video and audio; 4) the modern study material offers a high level of interactivity: the students can change the values of parameters in online calculations and visualizations or answer the questions with mathematical equations.

Based on the measurements, the traffic models for different e-learning components were built and are provided in more details in [38]. When study material was composed of HTML and GIF files, the communication traffic was low bit-rate, based on asymmetric bidirectional Transmission Control Protocol (TCP) packets with long periods between consecutive packet exchanges, caused by user’s access to next portion of material. The introduction of PDF files and growth of user’s connection bandwidth resulted in more “bursty” elastic network traffic. The enhanced multimedia elements, such as streaming audio and video, introduces unidirectional, more aggressive User Datagram Protocol (UDP) traffic with high constant bit-rate requirements that can significantly influence network traffic resources and system load, especially in the case of several simultaneous users. The consecutive requests of users working with modern interactive study material also cause an increased amount of TCP traffic carrying large amount of data in downstream, a result of online computations that produce large portions of data used for visualization and animations, as described in Section IV.

C. Survey Among Students

Students who participated in the survey [39] were asked to describe the process of working with the web-based material, its usefulness, the purpose of usage, and the way in which they used it. The survey was carried out among 280 first year undergraduate students. All students except one knew about the web-based material. The majority (75%) of them were told about the material by their teacher, and 20% by their colleagues. Surprisingly, 5% of the students claimed to have found it via searchers, such as Google or Yahoo.

Fifteen percent of the students affirmed that they studied all available web-based material. The majority (75%) used it to consolidate knowledge before exams. Fifteen percent claimed that the web-based material was their primary resource in preparing for the exam. Twenty percent of the students read directly from the screen, while 80% printed the material. Ten percent of students also printed the materials for their colleagues. Seventy percent used the system at home, while others used it on campus (23%) or somewhere else. The great majority of students found the system very useful and would like to have access to a similar collection of materials for other courses.
Most of the comments by students were very positive and encouraging. Nevertheless, they requested the capability for solving problems in a more detailed and structured way with dynamic and interactive web material, including the possibility of changing parameters in the online calculations.

D. Assessment of the Interactive Web-Based Methodology

The interactive web-based methodology has been employed in the course, Fundamentals of Electromagnetics, to provide prelaboratory background for the laboratory experiments [40] and also to support some online postlaboratory calculations. The material has been used in the winter semester of 2004/05 as a supplement to the traditional theoretical explanations in the classroom. The content was delivered through the e-learning system (E-CHO), which enables the collection of statistics on content usage for individual users. Student opinions also were collected.

A significant parameter is the number of students using the web-based materials in comparison to the attendance in the classroom (which is obligatory for students). From a group of 47 students, 38 (81%) logged on the system. Three students (6%) studied only the first few pages and stopped using the system (two of them dropped the laboratory course). Nearly half of the students (47%) visited all the prepared materials. Four students skipped the instructions for one of the laboratory experiments, while the rest studied approximately 90% of the total material. The average time students spent on the system studying the background of one laboratory experiment was 49 min, with individual times ranging from 21–150 min.

An index of student success was the number of students who submitted correctly solved laboratory course homework on time. Statistics from previous years indicate that approximately 85% of students who intended to attend the laboratory course submitted the laboratory on time. Around 60% of these students completed the homework correctly. During the winter semester of 2004/2005 when the system was available as a supplement to the traditional theoretical explanations in the classroom, in contrast, 96% of students submitted their work on time, and 89% of students had no mistakes in the homework they submitted.

The students also were asked to express their opinion about this new method of learning. The initial response was favorable. Most of them share the opinion that the web-based material offered them an opportunity to learn the hard-to-envision phenomena more quickly and effectively than if they received only handwritten materials. The motivation of the students also was increased because of their enthusiasm for web-based learning. They liked the opportunity to study at home at any time and to use the system interactively to complete and verify the results required for homework. Five of nine students who had never used the system claimed that they had no Internet access at home. They did not want to spend additional time at the University; some of them used printed versions of the results obtained from their colleagues, however.

The faculty staff did not notice a drop in attendance at the traditional class meetings. Some students studied the material in advance and brought printed versions of the material to the classes to seek answers to their questions. Nevertheless, the increased percentage of correct homework reduced the time required to review the submitted work. The faculty staff also observed a noticeable improvement, in comparison to previous years, in the students’ knowledge about performing laboratory experiments.

VII. CONCLUSION

This paper describes how to integrate state-of-the-art web component technologies through browser scripting and server-side applications into a modern web-based learning system that supports the presentation of key elements of engineering education: dynamic and interactive animations synchronized with the derivation of equations, parametric driven online computations and visualizations, and on-line tests that can be answered with equations. Such learning environments can be used for building self-study courses or supplements to traditional teaching methods and are excellent tools for stimulating and engaging students in further research.

The examples demonstrate the use of web-based educational material built with widely available technology components in a first year undergraduate course entitled Fundamentals of Electromagnetics. Because the effort required for developing the materials through integrating mainly existing components is reasonable and because students have expressed interest and requested additional features and material, development of the interactive and dynamic web-based learning environments described here will continue.

The application of the basic approach is not limited to the field of electromagnetics only and is useful in other fields of engineering and natural science.

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