Computer-Based Instruction on Multimedia Networking Fundamentals: Equational Versus Graphical Representation

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***Abstract*—Multimedia networking has been emerging in recent years as a strong driving force behind the expansion of the Internet. However, this topic is not commonly covered in the already content-intensive introductory networking courses. To facilitate student self-study of this novel topic the authors have developed a computer-based instructional module on the fundamentals of multimedia networking. In this paper, they describe the design and development of the module, which is aligned with Gagne's theory of instruction. They have developed two versions of the module—one with equation-based representation of the learning content and one with graph-based representation of the learning content. They have evaluated the two versions of the module with a total of 75 undergraduate, senior-level electrical engineering students, of which half were randomly assigned to the equational representation, and the other half to the graphical representation. They found that the graphical representation results in statistically significantly higher student performance on practice and post-test problems, shorter learning time, and more positive attitudes toward the computer-based instructional module.**

***Index Terms*—Computer-based instruction, equational representation, graphical representation, multimedia networking.**

I. Introduction

MULTIMEDIA networking is one of the main driving forces behind the expansion of the Internet. Video and audio streaming over the Internet are enjoying greater popularity and are accounting for an increasing portion of the total Internet traffic. With the rising importance of multimedia networking, educating electrical and computer engineering students at both the undergraduate and the graduate level about the fundamentals of multimedia networking becomes increasingly important. The introductory networking courses commonly offered by Electrical and Computer Engineering Departments at the senior and first-year graduate levels are typically devoted to introducing the students to the fundamental principles of the protocols and mechanisms in the five-layer networking protocol stack. The wealth of material to cover on the five-layer protocol stack leaves typically little or no time to teach novel topics, such as multimedia networking in the introductory networking classes. An attractive alternative to cover topics, such as multimedia networking, that do not fit into the class schedule is computer-based instruction. A self-contained, computer-based instructional module provides the students with flexibility in terms of the time, place, and pace of their learning process. The module can present the novel material in an interactive manner and provide the students with immediate feedback and instructional prompts. Such a computer-based instructional module can be assigned to the students as part of a homework or a class project. Also, the module could be presented in a senior design project class to complement the instruction on project design and management and to aid the students in the projects related to multimedia networking.

The pedagogical research on instruction, including computer-based instruction, has investigated the effectiveness of different content representations, mainly textual or graphical representations or combinations thereof, of the learning content, as detailed in Section II. The combination of multiple representations for learning is often referred to as *multimedia learning* [1]. In the context of engineering education, the learning content may often be represented in the form of mathematical equations or in the form of graphs. As detailed in Section II, the effectiveness of equational or graphical representation of engineering learning content has received relatively little attention.

In this paper, two main contributions are made:

- two versions are developed—one with equational representation, and one with graphical representation—of a computer-based instructional module that teaches the fundamentals of multimedia networking;
- the equational and graphical representation of the engineering learning content is investigated in terms of the performance on practice problems, learning time, post-test achievement, and learner attitudes for undergraduate, senior-level, electrical engineering students.

The instructional module introduces the students to the structure of a video-streaming system and teaches two specific objectives on how to determine the maximum video traffic backlog in the streaming server and the maximum video traffic delay from the video traffic characterization and the streaming rate. Following Gagne's theory of instruction [2], this module design includes a presentation of the learning objectives, the learning content, and practice activities with feedback and review of the learning content. All these components are instructionally aligned with the objectives and employ representation by mathematical equations in the equational version of the module and representation by graphs in the graphical version of the module.

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This investigation of the equational and graphical representation was conducted with a total of 75 undergraduate senior-level, electrical engineering students who completed the module as part of the EEE 489 Engineering Senior Design II class at Arizona State University. Half of the students were randomly assigned to the equational version of the module, and the other half to the graphical version. The performance of the students on the practice problems that are part of the computer-based instructional module, the time spent in the computer-based learning environment, the performance on a post-test, and the student attitudes toward the effectiveness of the module were collected and analyzed. With the graphical representation the learning time was statistically significantly shorter. The performance on practice and post-test problems were statistically significantly higher, and the attitudes were more positive as compared to the equational representation.

This paper is structured as follows. In Section II, the authors briefly review related work. In Section III, they describe the design of the computer-based instructional module. In Section IV, they describe the methodology for evaluating the two versions—with equational representation and with graphical representation—of the module. In Section V, they present and discuss the results from the evaluation of the two forms of representation. In Section VI, they summarize their conclusions.

II. Related Work

In this section overviews of the existing literature are given in the two broad areas most closely related to the study; namely, 1) the area of the design and development of multimedia learning modules for electrical and computer engineering and 2) the area of content representation for instruction and the related theory of cognition. The ubiquitous availability of multimedia computing on classroom and home computers has resulted in considerable interest in including multimedia instruction and learning into the electrical and computer engineering curricula [3]–[5]. The simple usage of computers, however, does not necessarily result in better education [6]. Rather the computer-based multimedia instruction needs to be carefully designed to employ effectively the various media channels, e.g., text, graphics, animations, etc., offered by the multimedia computing technology. Learner-centered design (LCD) which *scaffolds* the instructional content and engages the learner in active problem-solving, has been established as a basis for good design practice for such instructional modules [7]–[13] and is employed in this module design. Instructional modules for a wide variety of electrical and computer engineering topics have been developed [14]–[30], and instruction in the area of communication networks has recently received increasing interest [31], [32]. This module development is complementary to these works in that the authors develop a module for multimedia networking fundamentals for which no known computer-based module employing multimedia learning techniques exists.

The contemporary theory of cognition and learning that is relevant in the context of the present study of the equational and graphical representations is based on two key assumptions, namely, the *dual channel* assumption and the *limited working memory* assumption. The dual channel assumption [33], in brief, states that humans have two processing channels, one *verbal channel* and one *pictorial channel*. The verbal channel is assumed to process symbolic (abstract) representation of the content, such as spoken or written text, mathematical equations, and logical expressions. These are commonly referred to as *descriptive* representations, or *descriptors* of the content. Pictures, graphs, sculptures, and real physical models, on the other hand, are *depictive* representations, also referred to as *depictions* of the content, and are assumed to be processed in the pictorial channel. The limited working memory assumption [34], [35], in brief, states that each of the two channels can only process a limited amount of information at any one time, i.e., there is a limited working memory for each channel, as quantified in [36], [37]. Building on these foundations from the theory of cognition, a plethora of studies have evaluated the cognitive mechanisms and the effectiveness of learning from representations in the form of *words*, *pictures*, and combinations thereof [38]–[47]. A relatively wide range of knowledge domains has been covered in these studies, including the functioning of the human lungs, the process of generating lightning, and the mechanical functioning of brakes and pumps. The electrical engineering domain has received some attention in these studies; in particular, the insulation resistance test of electrical installations and the wiring (arrangement) of resistors in series and parallel have been considered [45].

On the other hand, representations involving mathematical *equations* have received relatively little interest. The studies [48], [49], which considered the content domains of Pascal's fluid pressure principle and simple interest calculation, have examined representations in the form of words, equations, or combinations thereof and compared the effectiveness of these representations with each other, but not with representations involving pictures/graphs. Note that if the assumptions of the outlined theory of cognition hold true, then these representations involving equations are processed in the verbal channel and do not utilize the resources of the pictorial channel. This study complements these existing studies in that the authors evaluate and compare the representation involving a combination of words and graphs with the representation involving words and equations.

The studies [50], [51] have examined how to represent the equations of elementary electrical circuit analysis in diagrams and compared the developed diagram-based representation with equation-based representation. There are a number of fundamental differences between this study and the studies in [50], [51]. First, the studies [50], [51] examined general instructional techniques for regular classroom instruction; whereas, the authors specifically focus on computer-based instruction. Second, the knowledge domain considered in the studies [50], [51] is elementary electrical circuit analysis (e.g., Ohm's law, resistance of parallel and series circuits, etc.), whereas the authors consider an advanced knowledge domain, namely multimedia networking fundamentals. Finally, the studies [50], [51] are primarily focused on developing ways of encoding (representing) the equations relating current, voltage, resistance, and power in static electrical circuits (i.e., the quantities are not functions of time) by graphical means. In contrast, the quantities considered in this multimedia networking module are functions of time, which can be naturally plotted over the abscissa as time axis and do not require specialized encoding techniques.

III. Design of Computer-Based Instructional Module

In this section, the design of the computer-based instructional module is described. The authors first specify the learning objectives and then present the instructional flow and the individual components in the instructional flow of the module.

A. Learning Objectives

The goal was to develop a computer-based instructional module that introduces electrical and computer engineering students without any specific prior knowledge in communication networks to the fundamental principles of multimedia networking. The goal was also to design the module so that it takes less than 40 minutes to complete, and could be integrated into a regular 50-min class session. To achieve these goals, the authors decided to develop a module that first introduces the students to the structure of a typical video streaming system and then teaches the two main objectives to determine 1) the maximum backlog of video traffic in the streaming server and 2) the maximum delay of video traffic in the streaming server. More specifically, the introduction to the video-streaming system presents to the students a model of a video-streaming system consisting of a camera, a streaming server, and the Internet connection to the video client, where the camera generates video frames of variable size (in bits) at a fixed frame rate. In the considered model the camera is directly connected to the streaming server, which immediately receives the generated video frames and streams them over the Internet connection, which is modeled by a fixed bandwidth pipe, to the video client. In the context of this streaming-system model, two main learning objectives are formulated.

- Objective 1: Given the video frame sizes generated by a video camera and the streaming rate, the learner determines the maximum backlog of video traffic in the streaming server.
- Objective 2: Given the maximum backlog of video traffic and the streaming rate, the learner determines the maximum delay of video traffic in the streaming server.

The motivation for the considered streaming-system model and the selected learning objectives is that they provide the novice learner with an introduction to the key mechanisms in multimedia networking in accordance with the relevant literature [52]–[57]. Also, from the key mechanisms taught in the module, the students can continue to explore the rich literature in multimedia networking with a solid understanding of the underlying key mechanisms.

In the computer-based module, Objective 1 is broken down into the following substeps. In each substep, the authors detail how the learners interact with the computer-based learning module in the equational (E) version and in the graphical (G) version. Because of the limitations of the available human–computer interface technology, another given—namely, a functional template in the equation-based version, and coordinate systems and graph segments in the graph-based version—is incorporated into the objectives.

1) In order to determine the maximum backlog of video traffic in the streaming server, the learner first expresses the amount of video traffic generated by the video camera as a function of time. In the equation-based version (E), this expression is constructed by filling in the functional parameters in the given functional template. In the graph-based version (G), the learner selects the appropriate graph segments.
2) In the second step, the learner expresses the backlog of video traffic as a function of time in the streaming server by subtracting the amount of served traffic from the amount of generated traffic for any given time. In the equation-based version (E), this expression is constructed by filling in the functional parameters in the given functional template. In the graph-based version (G), the learner fills in the vertical distance between the completed graph showing the amount of generated video traffic and the graph segment showing the amount of served video traffic.
3) In the third step, the learner determines the maximum backlog as the maximum over time of the function representing the amount of backlogged traffic as a function of time. In the equation-based version (E), the learner calculates the maximum backlog of video traffic in the streaming server from the completed functional template. In the graph-based version (G), the learner reads off the maximum vertical distance between the completed graph showing the amount of generated video traffic and the graph segment showing the amount of served video traffic.

B. Instructional Flow

Each version of the computer-based instructional module contains screens with subject matter information, examples, and practice activities, including feedback, that are directly aligned with the main instructional outcomes. The module consists of seven sections: Introduction (five screens), Video Traffic Backlog (11 screens in equational version, 12 screens in graphical version[1]), Backlog Practice (six screens), Backlog Review (two screens), Video Traffic Delay (three screens), Delay Practice (two screens), and Review and Conclusion (two screens), as illustrated in Fig. 1. This overall instructional flow was adopted in accordance with Gagne's theory of instruction [2], [58]. In the following, the authors describe the individual components in the overall instructional flow in more detail.

1) Introduction Screens: On the introductory screens, the learners are briefed on the importance of the domain area and learning goals, and on how to navigate through the computer module and how to interact with the practice activities. The main menu screen lists the objectives and the overall purpose of the program.

[1]The larger number of screens in the graphical version is a result of the graphs taking up more space on the screen compared to the equations. The instructional content is the same in both versions.

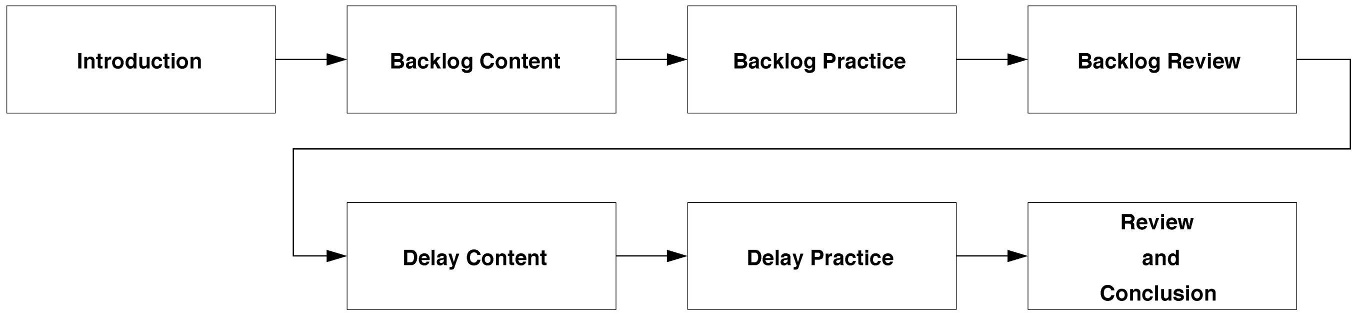


Fig. 1. Illustration of instructional flow.

2) Objectives and Instructional Content: At the beginning of each unit, the learners are given the objectives and the expected learning goals. The objectives are also accessible from the navigational menu and are written in nontechnical language to promote positive attitudes in the learners. The subsequent screens contain the instructional content.

In the Video Traffic Backlog section, the instructional content for the first objective is presented with examples. Two examples are included. The examples are presented in a step-by-step manner, with the amount of generated video traffic being presented first, then the amount of served video traffic, followed by the amount of backlogged video traffic. Figs. 2 and 3 show sequences of three screen shots of the two versions of the module. Both sequences of screen shots correspond to the second example for Objective 1. The learners proceed with the instructional content for the second objective in the Video Traffic Delay section that contains the new information and instructional examples. The instructional content in this section is built directly on the knowledge gained in the first objective.

The instructional content is presented with high levels of learner-content interactivity to maintain the learners' attention and interest. Throughout the content presentation the learners, among others, click on objects, input text/numbers, select "hot spots," and view animations. The design adheres to the basic CRAP (Contrast, Repetition, Alignment, and Proximity) principles. The screen layout, text format, and navigational buttons are consistent across the entire module leading to greater usability. Each unit has its name and the page numbers displayed to facilitate navigation.

3) Practice Activities: After each lesson, the learners are exposed to practice activities. The practice activities are designed to enhance the learning process. There are two sets of practice activities for each objective. The practice activities are structured exactly the same as the examples, only the surface features of the problems (e.g., number of frames, streaming rate) are different. The students input their answers to each presented practice question, and upon clicking "Enter" on the keyboard a feedback is revealed. The feedback informs the students on the accuracy of their response. In the case where the response is incorrect, the computer program offers the correct solution. For each first practice problem in each practice section if the student's response is incorrect, the feedback is accompanied by an instructional explanation that shows the process of generating the correct solution.

4) Review and Assessment: A review session follows the practice activities. The review section covers the main information as an abbreviated outline, presented in a bulleted list form for easy visual recognition. The review concludes the active learning phase of the module. The assessment of the learning outcomes is built outside the instructional module. The post-test items consist of word problems and require the learners to generate a solution. The problems are the same for all learners. However, the problem-solving strategies will typically differ, based on the version of the module with which a student interacted.

C. Module Development and Requirements

The module was developed using the Authorware 7.0 software, which is produced by Macromedia. The main rationale for choosing Authorware as a development tool is its ability to promote learner-content interaction. Another advantage is the plethora of publishing settings, allowing the program to be packaged as a capsulated executable module that runs on essentially all computer platforms and operating systems. The module is available from the Web [59] and can be distributed to students via the Web or CDROM. The module requires a computer with a processor that is equivalent or faster than a Pentium III processor, and at least 256 MB of RAM. The module has the VGA screen size of 800×600 pixels. The module can be executed with the free players available from Macromedia and does not require the installation of the Authorware software itself.

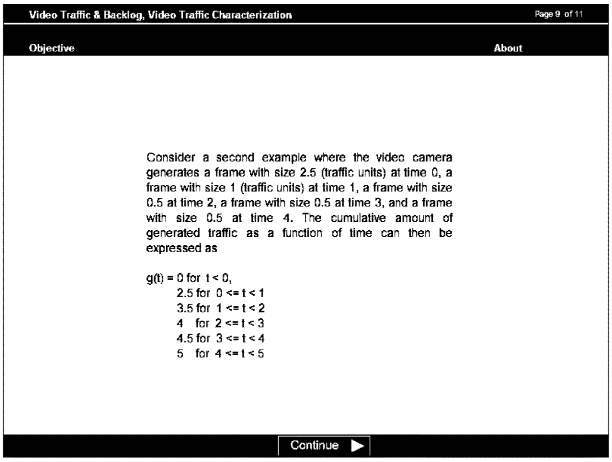
IV. EVALUATION METHODOLOGY

In the evaluation, the authors address the following research questions:

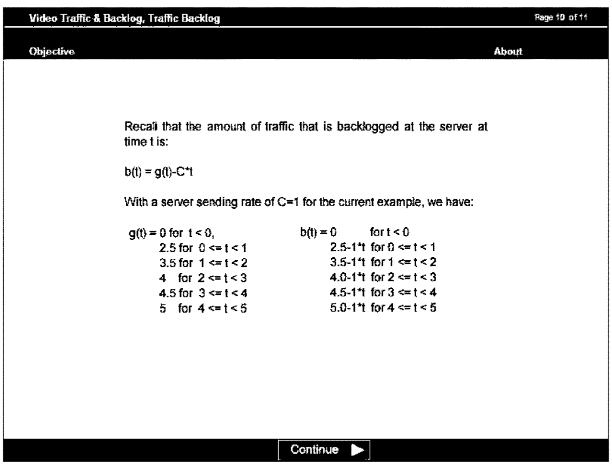
- What is the effect of the different forms of content representation—equational and graphical—on the learner's performance?
- What are the attitudes of the learners toward the different forms of content representation?

A. Participants

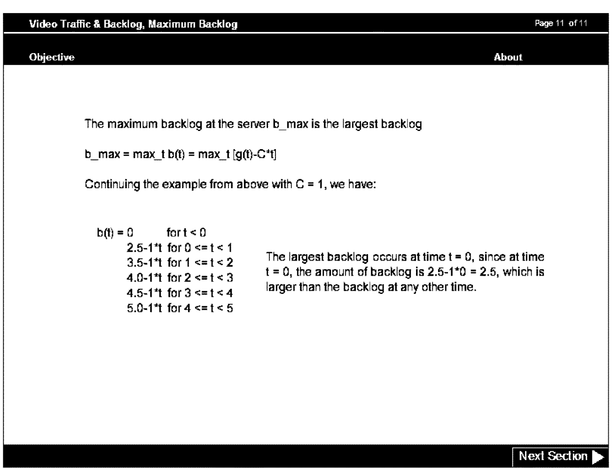
A total of 75 undergraduate students in the EEE 489 Engineering Senior Design II class in the Electrical Engineering Department at Arizona State University participated in the evaluation of the module described in the preceding section. The students were undergraduate seniors and had completed almost all



Sub-step 1) Express amount of generated video traffic as a function of time.

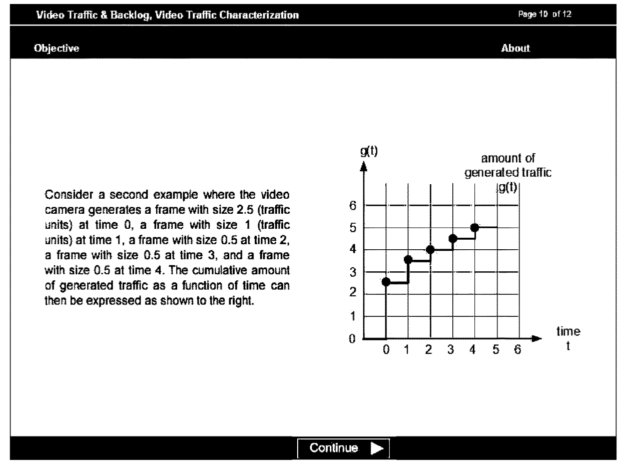


Sub-step 2) Express amount of backlogged traffic as a function of time.

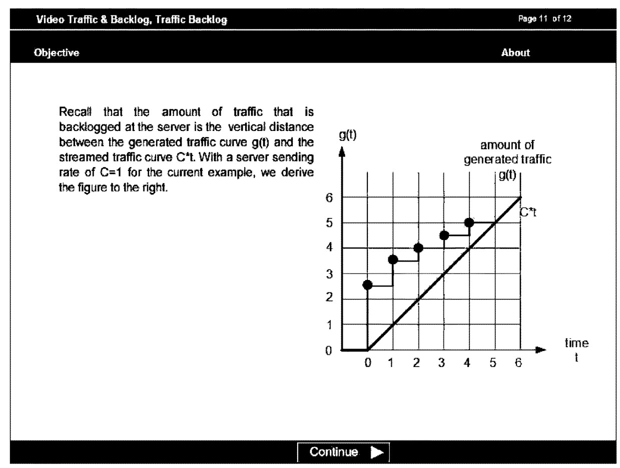


Sub-step 3) Determine maximum amount of backlogged traffic.

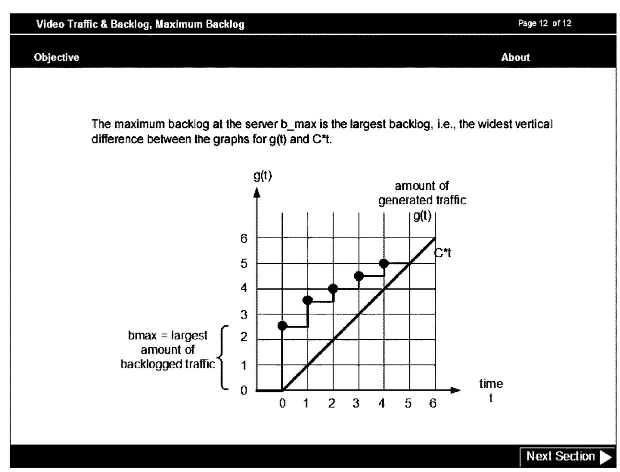
Fig. 2. Equation-based version of second example for Objective 1.



Sub-step 1) Express amount of generated video traffic as a function of time.



Sub-step 2) Express amount of backlogged traffic as a function of time.



Sub-step 3) Determine maximum amount of backlogged traffic.

Fig. 3. Graph-based version of second example for Objective 1.

required B.S. degree courses. The average age of the students was 25.24 years, and the age ranged from 19 to 45 years. There were 65 male and 10 female participants. The average GPA of the participants was 3.06 (standard deviation of GPA was 0.45). All students had the required entry-level behavior and knowledge that enabled them to learn from the computer-based program. None of the participants had any specific prior knowledge about multimedia networking fundamentals. The participants were randomly assigned into the two experimental groups. There was no statistically significant difference in the average GPA between the two groups. There were 37 participants in the equation-based version of the computer-based instructional module and 38 participants in the graphical-based version. Each student was identified by a unique experimental ID number in the evaluation study.

TABLE I
PRACTICE PERFORMANCE, LEARNING TIME, AND POST-TEST ACHIEVEMENT

	Overall $N = 75$		Equation $N = 37$		Graph $N = 38$	
Measure	M	SD	M	SD	M	SD
Practice performance (max. 24)	18.17	4.39	17.08	4.73	19.24*	3.81
Learning time (minutes)	22.68	7.73	24.57	6.77	20.84*	8.23
Post-test achievement (max. 38)	31.71	7.73	28.32	13.69	35.00*	7.09

* differs statistically from equation-based mean

B. Data Sources and Collection

Research data for the evaluation of the two versions of the instructional module were collected using 1) a paper-based demographic questionnaire, 2) the computer-based instructional module, 3) a paper-based post-test, and 4) a paper-based attitudinal survey.

1) Demographic Questionnaire: The questionnaire collected demographic data and information on prerequisite knowledge and entry-level behavior with eight simple questions. Specifically, students were asked to report their gender, ethnicity, age, GPA, and number of math courses while in college. The questionnaire also asked the participants whether they had learned about multimedia networking fundamentals earlier.

2) Computer-Based Learning Environment: The module was programmed to track the performance of each individual student on practice activities (a total of 24 practice tasks), and the total instructional time spent in the computer-based learning environment. The learners were permitted to navigate through the module in only one direction—namely forward (linear navigational pattern). With this linear navigational pattern the learning outcomes can be interpreted as a direct outcome of the instruction, i.e., the one-time exposure to the instructional content.

3) Post-Test: The post-test assessed student learning that was a direct result of interacting with the computer-based instructional module. The post-test contained three complex problems that required the students to perform the tasks that they had learned in the module, specifically determining the maximum backlog and delay of video traffic that is being generated by a video camera and, consequently, streamed by a video server and transported over the Internet. Participants could gain a maximum of 12 points (each) on problems number 1 and 2, and a maximum of 14 points on problem number 3, leading to a maximum score of 38 points to be achieved on the post-test. The post-test was an integrative test activity where the participants demonstrated their level of attainment of the two main instructional objectives. The format of the test items/problems was aligned with the conditions specified in the overall learning goals. The post-test was administered directly after completion of the computer-based module.

The purpose of the post-test being paper-based rather than computer-based (which would be more instructionally aligned with the computer-based instruction) is the complexity of tasks that students have to perform. In the computer-based instructional module, the learning was scaffolded by the inclusion of several givens (e.g., functional templates and graph coordinate systems). This scaffolding was beneficial in the initial phases of knowledge acquisition; however, to assess student learning accurately the instructors needed to see the students demonstrate their abilities to perform the complex tasks—as stated in the objectives—without instructional help and scaffolds.

4) Attitudinal Survey: The survey contained 15 five-point Likert-scale (rating from strongly agree, which was scored as 5, to strongly disagree, which was scored as 1) rating items. The items asked about the overall effectiveness of the computer-based instructional module. The students rated their agreement with the positive statements on the survey. The survey was to gather information that could be used to assess the students' attitudes toward the computer-based instructional module, its instructional components, the navigation, and content presentation. The survey also asked three open-ended questions concerning the most positive/negative aspects of the computer-based instructional module and suggestions for improvement of the module.

C. Procedure

The experimental study was carried out in two sessions that were one week apart. During the first session the participants filled out the demographic questionnaire. This initial session lasted approximately 10 min. The purpose of this initial session was to determine whether the students met the eligibility criterion of having no prior knowledge about multimedia networking fundamentals. One week later the experiment took place. The students worked individually on PCs in a school computer lab. After completing the computer-based module, the students were given the paper-based post-test, and then answered the attitudinal survey. This second session lasted approximately 40 min.

V. RESULTS AND DISCUSSION

In this section, the results for the evaluation of the two versions of the computer-based instructional module are reported and discussed. The main results for the performance on the practice problems, the learning time, and the post-test achievement are summarized in Table I. Throughout the report, the mean M and standard deviation SD of the performance measures are given. For the statistically significant differences between the graph-based group and the equation-based group, the authors report the F-ratio F with its degrees of freedom, the mean square error MSE, the statistical significance level p, and Cohen's f of the effect size.

A. Practice Performance

The overall average number of correct answers to practice activities was $M = 18.17$ $(SD = 4.39)$ out of the maximum score of 24, which represents a successful practice-solving

TABLE II
MEAN SCORES ON ATTITUDINAL SURVEY

Survey statement	Overall (N = 75)	Equation (N = 37)	Graph (N = 38)
I enjoyed learning from this computer-based instructional module.	3.95	3.76	4.13
I learned a lot from this computer-based instructional module.	3.65	3.51	3.79
I would like to learn more about multimedia networking.	3.88	3.92	3.84
I would recommend this computer-based instructional module to others.	3.83	3.70	3.95
I would like to engage in computer-assisted learning in the future.	3.75	3.68	3.82
The instructional content was presented effectively.	4.04	3.95	4.13
I benefited from the sequential presentation of the content.	4.09	3.89	4.29*
I liked the interactive presentation of the content.	4.09	3.95	4.24
Equation-based approach to teaching the concepts was/would be helpful.	3.97	4.03	3.92
Graphical-based approach to teaching the concepts was/would be helpful.	4.20	3.84	4.55*
There was sufficient amount of instructional examples.	4.09	4.11	4.08
There was sufficient amount of practice activities.	4.08	4.16	4.00
I felt comfortable using a computer as a learning tool.	4.32	4.22	4.42
Navigating and using this computer-based instructional module was easy.	4.44	4.38	4.50
Overall, this was a worthwhile learning experience.	3.96	3.86	4.05
TOTALS	4.02	3.93	4.11

* differs statistically from equation-based mean

rate of 75.71% for all participants combined. The participants in the equational version on average successfully solved $M = 17.08$ $(SD = 4.73)$ practice items, corresponding to a rate of 71.17%. The participants in the graphical version on average successfully solved $M = 19.24$ $(SD = 3.81)$ practice items, which corresponds to an average success rate on practice activities of 80.17%. The difference between the accuracy of practice problem solving of the participants in the equational and graphical versions was statistically significant, $F(1, 73) = 4.74, MSE = 18.38, p = 0.03$. Cohen's f statistic for these data yields an effect size of 0.25, which corresponds to a medium effect.

B. Learning Time

On the average the students spent $M = 22.68$ min $(SD = 7.73)$ in the computer-based learning environment. In the equation-based version the students spent on the average $M = 24.57$ min $(SD = 6.77)$ interacting with the computer-based program. In the graph-based version, the students on the average spent $M = 20.84$ min $(SD = 8.23)$ on the computers. This time difference was statistically significant, $F(1, 73) = 4.57, MSE = 56.96, p = 0.04$. Cohen's f statistic for these data yields an effect size of 0.19, which approaches a medium effect.

C. Post-Test Achievement

Overall, the participants learned much from the computer-based learning environment. The average total post-test score for all participants combined was $M = 31.71$ $(SD = 11.30)$ out of a maximum of 38 points, translating into a percentage score of 83.44% mastery level. The participants in the equational version on the average scored $M = 28.32$ points $(SD = 13.69)$ on the post-test, an equivalent of 74.54% mastery level. In comparison, the participants in the graph-based version on the average scored $M = 35.00$ points $(SD = 7.09)$ on the post-test, which translates into a mastery level of 92.11%. The difference on post-test achievement between the two experimental groups was statistically significant, $F(1, 73) = 7.09$, $MSE = 117.89, p = 0.01$. Cohen's f statistic for these data yields an effect size of 0.31, which corresponds to a medium to large effect.

For all participants combined, the average score for correctly solving post-test problems was $M = 9.93$ on problem number 1, $M = 10.37$ on problem number 2, and $M = 11.40$ on problem 3. These results indicate that on average the participants progressively improved their problem-solving abilities as they worked through the post-test problems.

D. Participant Attitudes

The participants' responses to the attitudinal survey are summarized in Table II. The Cronbach alpha across all survey items is $\alpha = 0.93$ indicating a high reliability of the survey. Generally, the participants considered the computer-based instructional module as good and effective. The total overall average attitudinal score was $M = 4.02$, showing that the participants agreed with the positive statements on the attitudinal survey. The highest rating was $M = 4.38$ in the equation group, which was for the statement "Navigating and using this computer-based instructional module was easy." This statement received the second highest rating $M = 4.50$ in the graph-based group. The highest rated statement in the graph-based group with $M = 4.55$ was "Graphical-based approach to teaching the concepts was/would be helpful." The lowest rated statement in both groups was "I learned a lot from this computer-based instructional module," which received an average score of $M = 3.51$ in the equational group, and $M = 3.79$ in the graphical group. (Recall that a score of 3 corresponds to "neither agree nor disagree" and 4 corresponds to "agree"; thus these lowest scores still indicate positive attitudes.) The participants in the graph-based group agreed significantly more strongly with the statements "I benefited from the sequential presentation of the content," $F(1, 73) = 4.38, MSE = 0.68$, $p = 0.04$, and "Graphical-based approach to teaching the concepts was/would be helpful," $F(1, 73) = 15.74, MSE = 0.61$, $p < 0.01$.

In the following, the received open-ended comments are summarized. The participants liked the efficient presentation of the instructional content, which consisted only of the relevant information, therefore, limiting cognitive load and preserving cognitive information processing resources. The instructional alignment was also highly praised by the participants. The step-by-step sequence of practice activities was perceived as beneficial by the participants. The participants enjoyed learning on the computers and acquiring the new knowledge at a self-regulated pace. The length of the program was perceived as optimal by the participants.

The participants enjoyed the least the inability to go back to previous pages/screens in the module. For the research purposes the participants were restricted to navigate only forward in the module. With this controlled form of the learning process, the learning outcomes could be interpreted as a direct result of the instruction (one time exposure to the instructional content). However, from the educational point of view, both forward and backward navigation would be preferable.

The participants suggested including voice in the instruction, added supplementary graphics and more difficult instructional examples. The participants also noted that it would be preferable to make the presentational window for the module comply with common expectations of Window's users, such as full screen, toolbars, etc.

E. Discussion

The two main research questions addressed in this study focus on the effectiveness of the equation-based versus the graph-based representation of the multimedia networking fundamentals and the attitudes of the learners toward these two forms of content representation in a computer-based learning environment. The results show that the participants in the graph-based group performed better on the practice problems in the computer-based learning module, spent less time learning in the module, and performed better on the post-test problems than their counterparts in the equation-based group; these differences were all statistically significant. Interestingly, the post-test scores of the graph-based participants had a considerably smaller standard deviation $SD = 7.09$, compared to the equation-based participants $SD = 13.69$. This discovery indicates that the individual participants in the graph-based group performed well fairly consistently on the post-test, whereas the post-test performance of the individual participants in the equation-based group was quite variable.

The authors offer the following interpretation of the better performance, i.e., higher scores achieved with less learning time, with the graph-based representation in the context of the theoretical models of cognition and learning. With the equation-based approach the learning content is represented by a combination of equations and words, both of which are essentially *descriptive* representations, i.e., *descriptions* of the content. According to the theory of cognition, in particular the dual-channel and limited capacity assumptions, descriptions are processed sequentially in the verbal channel, thus placing a high demand on the limited cognitive resources. In addition, the processing resources and working memory in the pictorial channel remain untapped. On the other hand, by expressing the content by a combination of graphics and words, both descriptive and *depictive* representations, i.e., both descriptions and depictions of the content are employed. According to the dual-coding and limited working memory assumptions of the theory of cognition, the descriptions and depictions are processed in parallel in the verbal and pictorial channels, thus exploiting the full processing capacity and working memory. As a consequence, a more effective utilization of the working memory is achieved, and the cognitive load is reduced, resulting in more effective learning. The authors may thus interpret their results as confirmation of the validity of the dual channel and limited working memory assumptions as indicators of learner performance for the considered content area (multimedia networking fundamentals) and content representations (combination of words and equations as well as combination of words and graphs).

The results from the attitudinal survey indicate that the participants in the graph-based group had, overall, somewhat more positive attitudes toward the computer-based instructional module. Interestingly, there was a statistically significant difference for the survey item relating to the helpfulness of the graphical representation. The participants in the graph-based group who had been exposed to the graphical content representation had significantly more positive attitudes toward this form of content representation than the participants in the equation-based group. Also, the participants in the graph-based group had a significantly stronger perception that they had benefited from the sequential presentation of the content. These results are consistent with the performance on the problems and may be interpreted as further validation of the dual-channel and limited working memory assumptions. By utilizing both cognitive channels the participants perceived a lower cognitive load and were overall more positive about their learning experience, especially the graphical content representation.

The results of the present study provide initial insights for setting instructional guidelines for electrical engineering education. Specifically, to utilize the limited cognitive resources and to maximize the efficiency of working memory, new knowledge should be well-structured and grouped into coherent chunks of information bits that are provided to novice learners in the form of graphical or pictorial representations. The authors derive such guidelines based on their evaluation with neophyte learners. Future research needs to test these assumptions with experts who already posses a high degree of content-specific knowledge. Graphical representations should concentrate only on the relevant facts and omit any extraneous information that would increase the cognitive load and, therefore, would require the learners to direct their limited cognitive resources to processing of such superfluous data.

They finally note that the gender distribution of the participants in the module evaluation was significantly skewed with 10 female and 65 male participants. This distribution is representative of the target population of the module, namely, senior-level undergraduate and first-year graduate electrical and computer engineering students, ensuring the validity of the evaluation results for the target population. Nevertheless, examination of the effectiveness of the module by gender may be of interest. The skewed gender distribution in this representative sample, however, does not permit for sound statistical means comparisons between the genders. The authors report, therefore, only the main descriptive statistics by gender. The ten female participants had a mean post-test score of $M = 36.50$ $(SD = 4.74)$

and a total mean attitudinal score of $M = 4.44$ ($SD = 0.43$), whereas the corresponding mean scores for the 65 male participants were $M = 30.97$ ($SD = 11.84$) and $M = 3.96$ ($SD = 0.61$). While these mean scores may appear to indicate that females achieved higher test scores and had more positive attitudes, such conclusions can not be supported by statistical tests and would need to be thoroughly examined in a future study specifically designed to compare genders.

VI. Conclusion

The authors have described the design and development of two versions—an equation-based and a graph-based version—of a computer-based instructional module on fundamentals of multimedia networking. The instructional flow in the module follows Gagne's theory of instruction. The module introduces students to the structure of a typical video-streaming system and teaches them how to determine the maximum backlog and the maximum delay of video traffic.

They have evaluated the effectiveness of the two versions of the module with 75 electrical engineering seniors. They found that with the graph-based version of the module the learning time of the students was significantly shorter, and the students achieved statistically significantly higher scores on practice and post-test problems compared to the equation-based version. Furthermore, the attitudes were more positive among the students in the graph-based version of the module.

Their evaluation results for the equation-based and graph-based versions of the module complement the existing evaluations of multimedia learning which have largely focused 1) on comparing content representations in words, graphics, and combinations of words and graphics with each other and 2) on comparing representations in words, equation, and combinations of words and equations with each other. In contrast, the authors have compared the representation with an equation-word combination with the representation with a graph-word combination, both of which are highly relevant and convenient representations for electrical and computer engineering content. Their evaluation findings provide initial evidence that the dual-channel and limited working memory assumptions of the theory of cognition apply to the knowledge domain considered in this study and its representation by an equation-word combination and a graph-word combination.

There are many exciting avenues for future work on the module design and development and research on the effectiveness of representations of electrical engineering content. One avenue for future module development is to include search capabilities, which would allow the learners to enter keywords and navigate to the pages that include that keyword. Further development could also address the suggestions expressed by the students in the open-ended comments on the attitudinal survey, as summarized at the end of Section V-D. An important avenue for future research on the representation of electrical engineering content is to examine the effectiveness of representations that combine words, equations, and graphs so as to provide foundations for guidelines on effective content representation for the electrical and computer engineering education field.

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