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Interactive online optics modules for the college physics course

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A new learning tool for geometrical optics is presented which has been developed for an algebra based introductory college physics course for life science majors. The interactive online learning module contains images, videos of problem solutions, short animated videos, and interactive animations, which allow students to actively explore the physics content beyond the pictures in a textbook. These elements are accompanied by narration and a transcript to guide the students while allowing them to navigate freely between the different parts of the module. The results of student learning, a comparison with a control group, and a survey of student attitudes toward this new instruction method are discussed.
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I. INTRODUCTION

Online physics teaching and learning resources, especially animations and simulations, are becoming more popular with both students and instructors. From commercial online homework systems such as, for example, MasteringPhysics, McGraw-Hill's Connect, or WebAssign[1] to PhET simulations,[2] a wealth of online material is available. Many physics instructors have also developed their own Java applets or Flash animations, and often make them available via digital libraries such as MERLOT[3] or COMPADRE.[4] Most of the online materials are stand-alone animations or simulations which can be used as supplements to a textbook, or in lieu of lecture demonstrations. If students are to use these animations and simulations on their own effectively, they often need additional instructions and hints on what to look for, or they require more physics context before the online material can make sense to them. For these reasons, most currently available physics online materials are not well suited for independent study without a connection to a traditional lecture or laboratory course.

Online multimedia modules which combine animations and audio have been developed at the University of Illinois for several areas in physics and are being extensively researched and tested.[5,6] The results are very encouraging, both in terms of student learning and student attitudes. Their implementation in a course where part of the instruction has been moved online (a hybrid-online course) has also been evaluated.[7] These multimedia learning modules presently contain animated videos with narration and embedded quiz questions, but no interactive animations or problem solutions, and still require instructors to cover these elements in the classroom.

Two interactive online optics learning modules have been developed at California State Polytechnic University, Pomona, which include a complete lesson for students to study entirely on their own. Their core part, the interactive animations and the questions in the narration, are intended to encourage students to take an active part in their learning, and not just passively absorb the material. The first online module, "Staying in focus—An online optics tutorial on the eye," was originally designed for middle school teachers.[8] The second module, "Refraction and lenses," was developed for our college physics course for life science majors, with the goal of replacing part of the lectures and ultimately to be implemented in hybrid-online courses.[9] This paper describes the refraction and lenses module and how it was incorporated into the course. Results of student learning and a comparison with a control group are presented, as well as student opinions, which were collected in an anonymous survey at the end of the course.

II. DESIGN OF THE ONLINE MODULES

Both online modules were created using the commercially available software, "SOFTCHALK," which provides a platform for easy online lesson design.[10] A SOFTCHALK lesson consists of "pages" ordered by tabs, between which the students can navigate freely. In the refraction and lenses module, each page contains one of the following elements: graphics or still pictures, animated videos (linear animations), interactive animations, and videos of textbook problems being solved.

A. The cognitive theory of multimedia learning as a design guideline

According to the cognitive theory of multimedia learning,[11] our brains receive information via visual and auditory senses. By combining words with pictures in learning materials, both the retention of the information and the transfer, that is, the mental integration with the learner's prior knowledge, are greatly enhanced. This behavior was acknowledged by providing narration on every page of the tutorial, so students can simultaneously listen to the audio and watch the animation or graphics. The results of studies on online learning[12] are consistent with our students' own assessment. Because the human mind has a limited capacity of acquiring and processing information, each page of the tutorial was limited to the essential information, without any material that might embellish the looks, but distract the learner.

The human brain has the ability to actively process the information it receives, rather than simply recording and memorizing it. Ideally, learners mentally integrate the verbal and visual representations of the new information and build meaningful connections to their prior knowledge. To foster this type of active cognitive processing in the interactive animations, students are frequently encouraged to manipulate objects on the screen with the mouse, and to make observations on what happens. Also, connections between the new physics material to be studied and their everyday life experiences are made (for example, eye glasses).

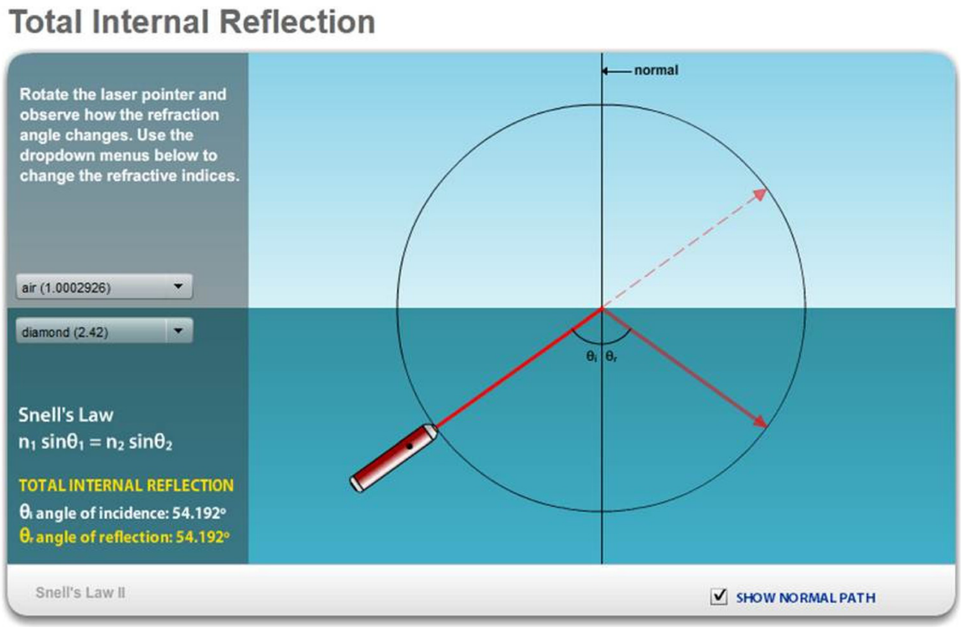

Fig. 1. Screenshot of the interactive animation on total internal reflection. Students can rotate the laser pointer 360° and observe how the angle of refraction changes and the conditions for total internal reflection.

All narration is accompanied by a transcript or closed captioning (for the videos), and text for screen readers is provided with all images in accordance with accessibility requirements for people with disabilities. The different elements of the online modules are described in detail in the following.

B. The elements of the online modules

The refraction and lenses module consists of 18 pages ordered by tabs. The use of tabs puts learners in control of the pace of their studying, an important aspect in the design of online learning tools which has been shown to make learning more effective.[13] In contrast to the multimedia learning modules of the University of Illinois, which consist of linear animations plus quiz questions, our online modules contain four elements: interactive animations, linear animations, videos of problems being solved, and pages with graphics. Quizzes were not implemented when the modules were first tested.

The interactive animations are the core elements of the online modules for two reasons: They engage the students to be actively involved and can provide insight into the physics beyond the pictures in a textbook. For example, in the interactive animation on making a virtual image with a convex lens, students can move the object, a candle, with the mouse and observe what happens to the position and size of the image in a principal ray diagram. The module contains five interactive animations: the law of refraction, total internal reflection, and principal ray diagrams for a convex lens, real images only, for a concave lens, and for a convex lens, virtual and real images.

By allowing students to perform virtual experiments and to explore the presented concepts, the interactive animations foster active learning and active cognitive processing of the material. To quote one student: "I really enjoyed the modules because I could spend as much time as I needed playing with them and moving them around until I was confident that I understood the material." Another student wrote in the survey: "With Lenses, seeing the image moving back and forth as the object is moved along the axis is WAY more valuable than remembering a pneumonic (mnemonic) device for what happens to the image as the object is at particular location."

Figure 1 shows an example for the design of an interactive animation, a screen shot of total internal reflection. It displays a horizontal interface between two media with different indices of refraction, which can be selected from eight different choices from a drop-down menu. The colors of the top and bottom regions adjust automatically with each selection of media such that the region of higher index of refraction shows the darker blue color. Users can move a laser pointer in a full circle using the mouse, and the laser beam is refracted at the interface according to the law of refraction. Students can observe, both qualitatively and quantitatively, refraction when a light beam enters a medium of different index of refraction, explore under what conditions total internal reflection occurs, and "measure" the critical angle for combinations of different media.

The five linear animations of the refraction and lenses module are flash videos with narration, which play by themselves once the big arrow on their page is clicked. No further user interaction is required or possible. Unlike the pictures in the textbook, these videos can show how an idea is developed. For example, in the linear animation on how an image is formed by a convex (concave) lens, students can observe how an image is constructed as the three principal rays are traced out one by one while the reasons for their specific paths are explained.

In the survey, students were asked to compare this animated derivation with the textbook[14] presentation of the derivation of the principal ray diagram for a concave mirror. More than 75% of the students agreed with the statement that the linear animation helped them to understand the derivation better than the textbook.

The refraction and lenses module also contains four videos which demonstrate the step-by-step solution of a textbook problem. The videos were made with a document camera directed on a sheet of paper where a sketch of the problem is drawn and the calculations are performed. As in the linear animations, these videos emphasize the process of solving the problem and provide users with audio (and transcripts). When asked to compare the problem solving videos with the solved problems in the textbook,[14] more than 75% of the students agreed with the statement that the videos were more useful for their learning.

Four of the pages consist of still pictures with narration; for example, a welcoming message and a summary page with a table of the sign conventions and image types for concave and convex lenses. Their main purpose is to convey factual information, and they are embedded in the learning material. As an example, the still image page with the equations for the derivation of the thin lens equation follows an animated video demonstrating the ideas of the derivation. Students are encouraged to pause at the end of the video to work out the equations themselves before proceeding to this solution page.

III. IMPLEMENTATION OF THE ONLINE MODULES AND RESULTS OF STUDENT LEARNING

The online modules were used for the first time at Cal Poly Pomona as part of our college physics course for life science majors, for one section in the spring quarter 2010, and for two sections in the winter quarter 2011. This course is the second in a sequence of three quarters with each section typically having around 50 students. The subjects covered are waves, optics, and heat. The class meets twice a week for two 75 min lectures. During the first four weeks of the quarter, one (in spring 2010) or two (in winter 2011) lectures were replaced by the online modules. Before the students started working with the refraction and lenses module, they took an eight-question multiple choice pre-test. This test was designed by the author, because a generally accepted conceptual optics assessment (analog to the Force Concept Inventory for mechanics) was not available at this time. The questions were conceptual and did not require any calculations, for example: "A light ray experiences total internal reflection at the interface between medium A, in which it propagates, and a medium B. Which medium has the higher index of refraction?"

A total of 139 students (out of 150 students registered in the three sections) completed the pre-test, which was given before the start of optics instruction in lecture or laboratory, and received participation credit for it. The post-test was administered as part of a closed book/closed notes in-class exam without further lectures in geometrical optics, and took place before the students performed the corresponding optics experiments in lab. The number of correct answers increased significantly from pre- to post-test, with the average rising from $39\% \pm 19\%$ to $76\% \pm 16\%$.

In the summer quarter 2011, the same multiple choice pre-test was administered to a control section of the course that did not use the online modules and was taught in a traditional manner by an experienced instructor. The pre-test was given to the control group before lecture instruction on optics, but after the students had completed two optics experiments as part of the laboratory, which is a co-requisite of the lecture course. Although the pre-test results of the two groups are similar (control group pre-test average $40\% \pm 16\%$), the class sections which used the online modules performed better in the post-test than the control group, which achieved an average score of $52\% \pm 20\%$.

Figure 2 shows histograms of the number of correctly answered questions for the pre- and post-tests. Although these results suggest that the conceptual understanding of the students who used the online modules is higher than that of students with traditional instruction, further studies are necessary to test and compare student performances in problem solving.

IV. STUDENT ACCEPTANCE AND OPINIONS

In an anonymous survey completed by 146 of our students, they were asked how much time they spent studying

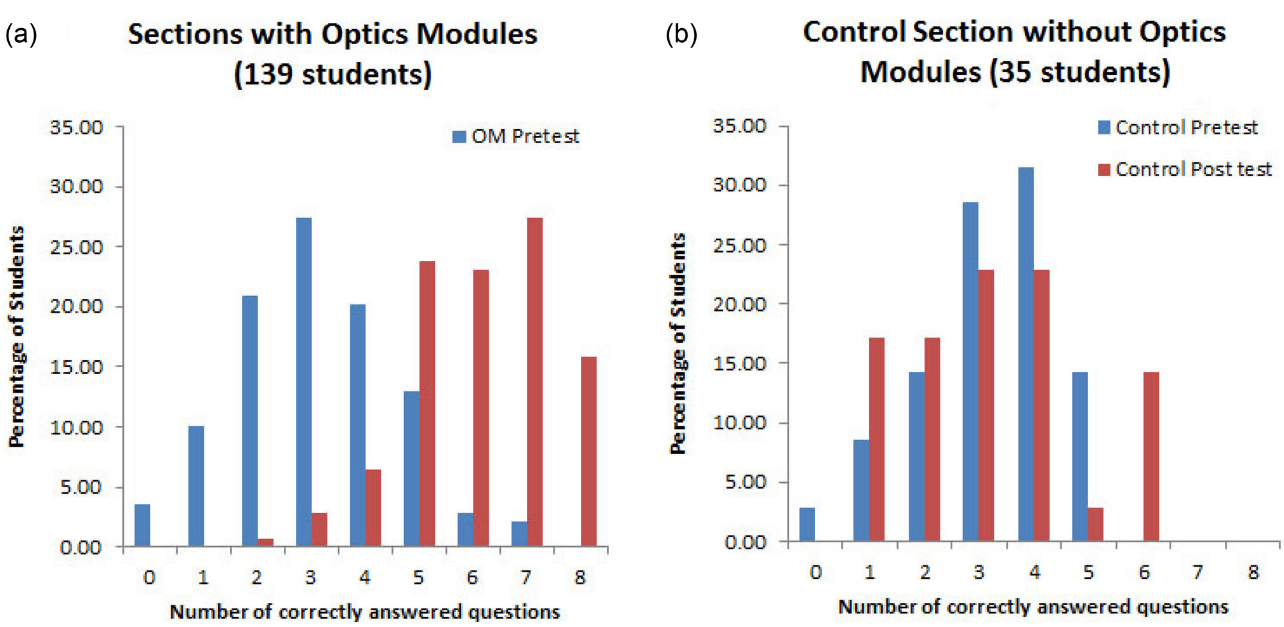

Fig. 2. Histograms of the number of correctly answered questions for pre- and post-tests, for sections (a) with and (b) without optics modules. The scales of the two graphs are identical, with the y-axis displaying the percentage of students which answered correctly.

Table I. Results of the student survey on the online modules. To provide a quick qualitative overview of the results, the third column shows the percentage of students who either agreed or strongly agreed with the given statement.

Questions asked in student survey	Likert scale	(Strongly) agree
Studying the Online Optics Modules was *more interesting* to me than reading the corresponding chapters in our textbook.	4.1 ± 0.7	84%
The interactive animations in the Online Optics Modules helped me *understand the material better* than reading our textbook.	4.2 ± 0.7	87%
I think the "Refraction & Lenses" Online Module was *as useful* for my learning of this material as a *face-to-face lecture* would have been.	3.1 ± 1.0	neutral
I *liked* working with the Online Optics Modules.	4.0 ± 0.8	78%
After working with the "Refraction & Lenses" Online Module, I feel *well prepared to do the homework* problems on this material.	3.4 ± 0.9	56% (29% neutral)

the online modules, and their opinions about the usefulness of these learning tools. For the refraction and lenses module, 35% reported that they spent 20–40 min studying it, 45% spent 40 min to 1.5 h, and another 12% spent even longer. For the tutorial on the eye, the numbers were 40% (20–40 min study time) and 40% (40 min to 1.5 h study time). A study time of less than 40 min seems too short for the average student with little or no prior knowledge of the subject to thoroughly understand the material. Working through the online modules for at least 20 min is sufficient for students to be able to form an opinion about the learning material. Because more than 90% of them spent at least this amount of time on the refraction and lenses module, we conclude that the results of the survey on their opinions are meaningful.

Table I shows a summary of the results for some of the survey questions. The questions were posed using the Likert scale, which has answers ranging from five (strongly agree) to one (strongly disagree). Nearly 90% of the students agreed or strongly agreed that the interactive animations helped them to understand the material better than reading the textbook. More than 80% believed that studying the modules was more interesting than reading the corresponding chapter in the textbook, and nearly 80% liked working with the online modules. When asked to compare the usefulness of the online modules to that of a lecture on the same subject, opinions were split, with the average answer neutral, with a large standard deviation. Nearly 40% agreed with the statement "The online module was way more/somewhat more useful than the face-to-face lecture would have been," and about 33% selected "The online module was as useful as the face-to-face lecture would have been." Only 25% found lectures (somewhat or much) more useful than the online modules—a strong vote for this new learning tool. Student opinion was also split on the question how well the online modules prepared them to do the homework problems, with the majority agreeing or strongly agreeing that they felt well prepared, and nearly one third of the students giving a neutral answer (neither agreeing nor disagreeing); less than 12% did not feel well prepared.

Students were also asked if they had any comments or suggestions for improvement of the online modules. Most of their comments were very positive: "It was definitely more helpful, and less confusing, than the material in the book." "It was like having the professor right in my living room!" Several students suggested that more videos of problems being solved be included. This suggestion is not surprising, because students usually believe that the more problems they solve (or observe being solved), the better prepared they are for the exam.

Several students stated that they liked the online modules as a supplement to the book and lecture, and most of them liked the fact that they could go back and re-view the material as often as they needed. However, many students still would prefer to learn the material in a traditional lecture setting. To them, the main drawback of the online modules was that they could not ask questions and receive immediate feedback. When the instructor solicited questions about the online module material at the following lecture, none were asked although the students were explicitly asked to write down their questions while studying the online modules. The problem seems to be psychological. Many students believe that asking questions and receiving immediate feedback is essential not only for their success but also for their comfort in studying. To alleviate these concerns, a discussion board linked to the online modules could be set up, as one of our students suggested. A discussion board would give students the opportunity to obtain feedback from their peers almost immediately, and from the instructor within an announced time frame. In addition, it might be possible in the future to implement answers to frequently asked questions that appear when the students enter a keyword.

V. DISCUSSION

Interactive online modules have been discussed as a new learning tool for geometrical optics to allow students in an algebra-based introductory physics course to study the material on their own. The results of student learning are encouraging. The course sections with the online modules performed better in a multiple choice test than a traditionally taught section. Student acceptance of this online learning tool is very high. Students enjoy using the interactive animations, and most believe that they can learn more from the online modules than from a book. More than 70% considered the online modules as valuable or more valuable for their learning as a lecture. This percentage could likely be increased by giving the students the opportunity for more immediate feedback embedded in the online materials. Although further investigations on conceptual understanding and problem solving are necessary, this study demonstrates that online optics modules are a promising tool for student learning of geometrical optics independently of a traditional course.

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[4]The ComPADRE digital library is a network of free online resource collections supporting faculty, students, and teachers in physics and astronomy education, <www.compadre.org>.
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