INTEGRATION OF FORMATIVE ASSESSMENT INTO ONLINE ENGINEERING ASSIGNMENTS

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Abstract

Online homework assignments containing formative diagnostic feedback have been developed with the VaNTH Courseware Authoring and Packaging Environment (CAPE) and are delivered to students via the VaNTH experimental Learning Management System (eLMS). Our goal is to construct online quantitative engineering assignments that provide students with immediate assistance as they encounter difficulties in working problems. This is in contrast to the usual procedure in which several days transpire between the time problems are submitted and the time students receive feedback in the form of corrected papers and/or posted solutions. Comments written on homework papers are often cryptic and illegible. With the online system, students receive their grade immediately upon completion of the assignment and, since input variables can be randomized, each student receives a unique numerical problem. The system frees the Teaching Assistant (TA) from grading homework in favor of helping those students who are having difficulty solving the problems. Students who cannot work the problems are asked to see either the instructor or the TA to obtain additional help. Students and instructors can review the student's pathway through the assignment using eLMS, making it easier to discover where they went wrong. This assists the students who most need it and also helps the instructor identify additional diagnostics that can be used to improve the feedback offered to students who make the same mistake in the future.

Introduction

Formative assessment is one of the most effective instructional methods for supporting student learning.[1] Formative assessments provide students and instructors with continual feedback on students' progress toward the learning goals. We have used the Personal Response System (PRS)[2,3], an electronic communication system, to provide formative feedback in the classroom. Although the PRS system enhances the overall learning experience for the class as a whole, it does take some class time, particularly on the more difficult concepts, and may not be beneficial to the brightest students, who may be forced to sit through several iterations of unneeded remediation.

Homework assignments are designed to provide students with the opportunity to apply a number of concepts that have been presented in class to different systems. Although the intent of such assignments is to provide the student with formative assessment, the lag time between when the concepts are presented in class and when the graded assignment is returned to the student is often as long as two weeks. By that time, additional problems which build on concepts covered by the original assignment may also be assigned. Students can easily fall behind if they encountered difficulties in earlier assignments, particularly if they don't recognize the errors themselves.

We hypothesize that effective real-time formative assessment will lead to better use of time for students and instructors, and will provide instruction that is more focused on understanding at the level of each individual student. Online assignments with automatic grading should serve to shift the primary role of teaching assistants from graders to authentic teachers and true assistants in the composition of diagnostic homework. Technology-enabled enhancements that provide feedback can shift the instructor's role from pedagogue ("sage-on-the-stage") to consultant, facilitator, and collaborator, allowing students to take greater responsibility and control over their learning. Another advantage is that instructors can assign optional practice problems without the need to collect or correct them.

We built online modules that could provide individualized, formative feedback outside the classroom. Good students would need little or no remediation, and the module might even provide them with more challenging problems. Intermediate students should be able to finish the problems within one or two iterations with the help of the formative feedback provided by the module. Students who are unable to work the problems with the aid of the module are asked to see the instructor or TA for help.

Instructional Design Methods

We used the VaNTH Courseware Authoring and Packaging Environment (CAPE)[4] to develop the materials described here and an experimental Learning Management System (eLMS) developed by VaNTH[5] was used to deliver them to the students. The CAPE system provides a highly flexible authoring environment that can be used to design learning activities. These activities can be a simple linear presentation of content or a highly interactive lesson where the system presents new information to students based on the decisions students make during the lesson. These learning activities can be assigned as part of students' pre-class preparation or as a post-class homework assignment. They can also be used in computer-enabled classrooms to provide additional resources and capture students' responses to questions asked in class. The eLMS system can automatically grade assignments and track, over time, students' progress toward understanding critical concepts.

Our general approach for developing online homework problems is illustrated in Figure 1. A problem statement is presented to the student along with appropriate resources that they may need. The module can be set so that each student works a different numerical problem. Students use paper, pencil, calculator, computer and other resources to solve the problem, and submit their result via eLMS. The module checks their answer against the correct solution, and if it is within a preset range, will inform the student that their result is correct, provide them with their grade, and thank them for completing the assignment. If the answer is not within the acceptable range, the system checks to see if the student has exhausted the allotted number of attempts. If not, the student is provided with diagnostic feedback, based on the types of errors that students commonly make when attempting this problem. The feedback can be static or dynamic. Dynamic feedback is based on answers provided previously by the student and/or on the number of times the student has answered incorrectly. In cases where the final result is reached via a series of computations, the module will often break the problem into smaller steps to see where the student has gone astray. The number of attempts a student is allowed for each step and the grade associated with each step can be set by the instructor. Students continue to interact with the module until they either get the correct result or they have used all of their allotted attempts. In the latter case they may be provided with the solution (if a practice problem) or asked to see the instructor or TA to receive help with the problem.

A simple example from solid mechanics is provided in Figure 2. Figure 2a shows the problem statement, while Figure 2b shows the CAPE module. Students need to apply two equations: 1) the definition of normal stress, and 2) the definition of the safety factor. Students commonly make five types of mistakes when computing the maximum allowable force: 1) inverting the definition of the safety factor, 2) neglecting the safety factor altogether, 3) forgetting to convert units from mm^2 to m^2, 4) forgetting to convert units from MPa to Pa, and 5) submitting their result as stress instead of force. These are captured within the "Diagnostics" phase of the module shown in Figure 2b. Messages that are provided to

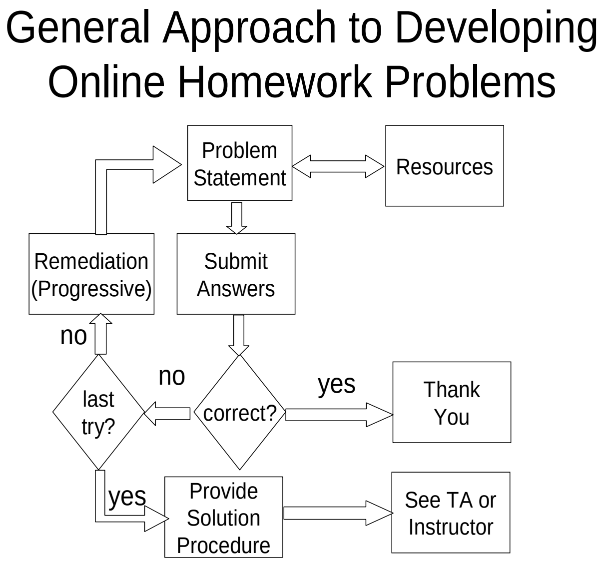


Figure 1.

students on their first and second attempts are listed in Figure 2c.

A second example illustrates a case where the final result is reached via a series of computations and the module has broken the problem into smaller steps to see where the student has made an error. Figure 3 shows a module that checks a student's computation of the mass moment of inertia for the thigh+leg+foot combination. If the student enters an incorrect value, the module proceeds to check each step in the calculation, starting with the masses the student used for each body part. For example, it is possible the student used anthropometric tables for a female, rather than a male. The module then systematically checks the intermediate values computed by the student for the mass moment of inertia for the thigh, leg and foot about the hip. In the latter two cases the student must apply the parallel axis theorem. Figure 3 shows the dialog presented to students as the module checks the intermediate computation for the moment of inertia of the leg about the hip. If their response is incorrect, the module proceeds to further diagnose this intermediate calculation, providing additional feedback based on the values the student used to make the computation. It performs the same diagnosis on the student's computations for the foot, and then gives the student another opportunity to compute the mass moment of inertia of the composite body.

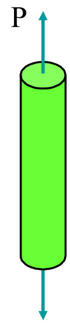
Understanding the subscript and sign convention for shear stress and normal stress is a difficult concept for many sophomores. This has been verified through the use of formative assessment in the classroom.[2,3] Considerable time and effort has been expended by the lead author in reviewing this topic in the classroom. Unfortunately, students who initially understand the concepts are also forced to undergo the same extensive remediation in the classroom as those who have difficulty with the concepts. To help overcome this problem, and to reduce the amount of class time taken in reviewing these concepts, we developed a CAPE module that provides students with an opportunity to practice the subscript and sign conventions for shear stress and normal stress in two dimensions. The module interface is shown in Figure 4. Resources provided within the module include pop-up windows that explain the sign and subscript conventions. Completion of an assignment requires that a student correctly identify the shear stress and normal stresses on each face three times in a row. The x and y coordinate directions, the directions of each of the stresses, and the magnitudes for each stress change randomly with each iteration. Students who do not understand the conventions are unlikely to guess the correct values three times in a row, and since the problems are randomized, they cannot copy the answer from another student's module. The only sure way to complete the assignment is to learn the conventions.

Basic vector manipulations are course prerequisites for many engineering courses. However, quizzes given on the first day of class often indicate that students have difficulty performing simple vector operations. We used CAPE and eLMS to develop an online vector tutorial to help students review these important topics[6]. This assignment is made after

Figure 2. A simple example of an online homework problem in solid mechanics: a) problem statement; b) CAPE module; c) diagnostic feedback for two iterations.

a)

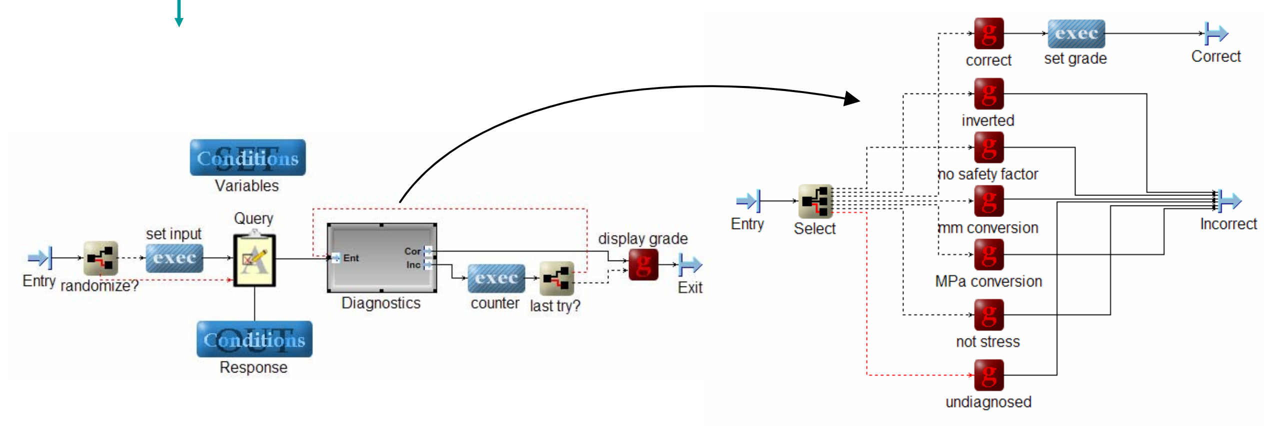
Maximum Allowable Force



What is the maximum allowable force, P, if:

Safety factor = 3
Ultimate Stress = 150 MPa
Area = 8 mm^2

b)



c)

expression	message (iteration 1)	message (iteration 2)
A*sigma_u/SF	That's correct	That's correct
A/(sigma_u*SF)	You appear to have inverted allowable stress and ultimate stress in the definition of the safety factor	You appear to have inverted allowable stress and ultimate stress in the definition of the safety factor: $SF=\sigma_{ult}/\sigma_{max}$
A*sigma_u	It appears that you forgot to include the safety factor in your calculation	It appears that you forgot to include the safety factor in your calculation, $SF=\sigma_{ult}/\sigma_{max}$
10^{6}*A*sigma_u/SF	You appear to have forgotten to convert area units from mm^2 to m^2 when computing force from stress	You appear to have forgotten to convert area units from mm^2 to m^2 when computing force from stress: 1 mm^2 = 10^{-6} m^2
10^{-6}*A*sigma_u/SF	You appear to have forgotten to convert stress units from MPa to Pa when computing force from stress	You appear to have forgotten to convert stress units from MPa to Pa when computing force from stress: 1 Pa = 1 N/m^2 = 10^{-6} MPa
sigma_u/SF	We are looking for the maximum force, not the maximum stress	We are looking for the maximum force, not the maximum stress, $P_{max}=\sigma_{max}A$
UNDIAGNOSED	We are looking for the maximum force P_{max} that can be applied with a known safety factor SF:	We are looking for the maximum force P_{max} that can be applied with a known safety factor SF: $SF=\sigma_{ult}/\sigma_{max}$, $\sigma_{max}=P_{max}/A$

Figure 3. Diagnosing a complex problem by breaking it into multiple parts.

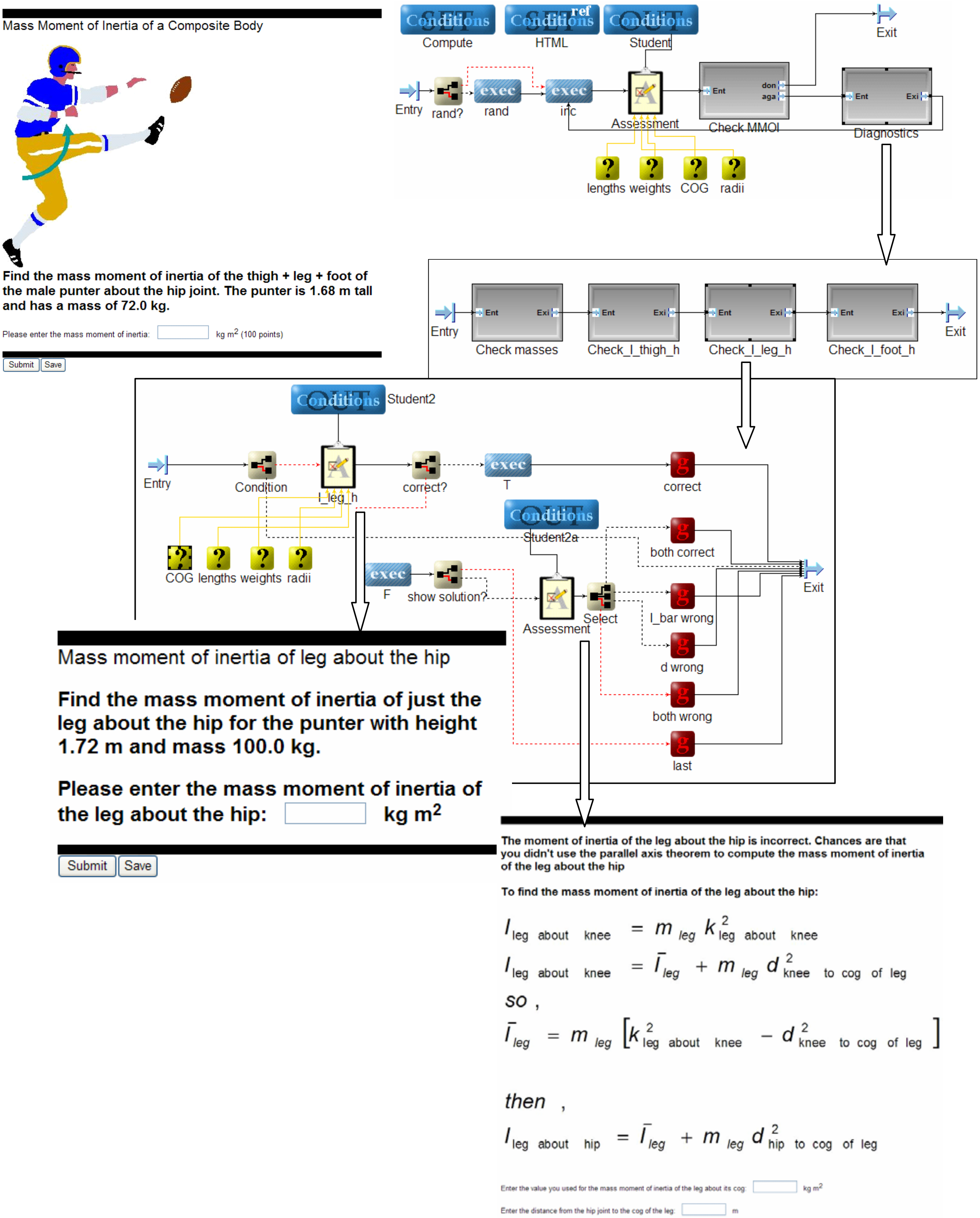
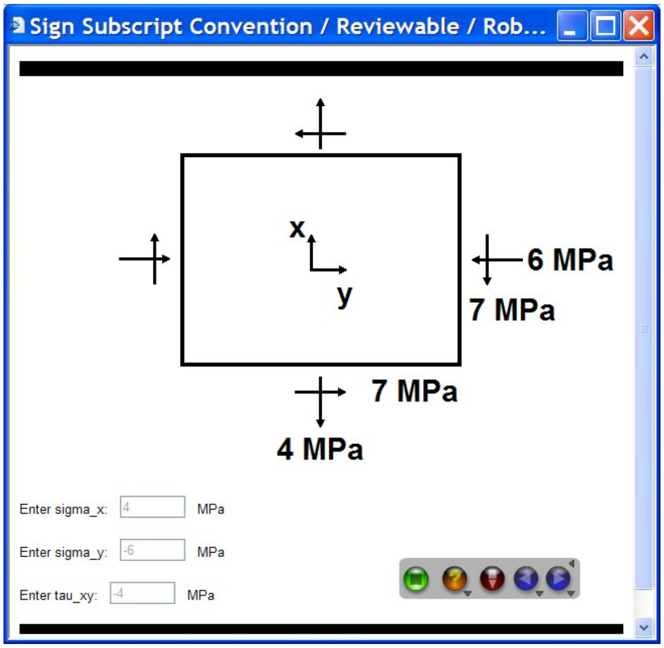


Figure 4. a) eLMS delivery interface for a CAPE module designed to instruct students in the sign and subscript conventions for normal stress and shear stress.



students have taken an in-class pretest. The vector tutorial covers all of the important vector operations in basic mechanics including addition, subtraction, unit vectors, direction cosines and vector products. The tutorial is followed by a posttest, identical in form to the pretest, in which the input variables are randomized so that each answer is unique.

The Vector Addition Module is another example that provides the student with formative feedback as they perform vector addition. Two vectors with randomized magnitudes and directions are presented to the student in the context of a biomechanics problem. The students are asked to enter the magnitude and direction of the resultant vector. If they get both correct, they are congratulated and the next assignment is presented. If they do not get the correct vector magnitude, their answer is compared with conceptual and mathematical errors commonly made by students, such as forgetting to take the square root of the sum of the squares, or reversing the x- and y- components of the vector. If the student's answer matches one of the common difficulties, then a simple statement such as "You may have reversed the x- and y- components of one of the vectors" will be displayed, and the student will be given a second chance. If the student misses the magnitude a second time, more information is displayed (e.g., a diagram and the equations needed to compute the components of the missed vector). If the student misses it a third time, the complete solution, including all intermediate steps, is provided so the student can see exactly where he or she went wrong. Similar diagnostics is performed on computation of the vector direction.

We have developed over 30 such modules containing diagnostic feedback in the areas of biomechanics and biotransport. These modules have taught us a great deal about how to use CAPE and eLMS to provide timely and meaningful feedback to students while they attempt problems outside of the classroom. The objective of this approach is to provide students with immediate assistance as they encounter difficulty in working homework assignments. Students who do not answer problems correctly are asked to see the professor or the TA. When they come to the office, we review their online delivery record and attempt to understand the error or misconception that the student made while working on the problem. If this appears to be an error that other students may make in the future, we will include it in the diagnostic scheme. Thus, over time, we will accumulate a rich set of diagnostics that can be applied to many different types of problems. At the same time we will develop an extensive set of online homework problems.

Assessment of Technology-Based Online Learning Activities

A comparison of student performance on a final exam question in an introductory biomechanics class dealing with sign and subscript conventions in 2003 (without module) with the same question asked in 2004 (module assigned) is shown in Figure 5. The time spent in class on the sign and subscript conventions was the same in both years. We believe the online module was at least partly responsible for improving the average score on this question from 38% to over 80%. Improvements were also observed on final exam problems in which students computed the centroid of a composite body. We believe that the introduction of two online diagnostic modules in 2004 that dealt with this topic was partly responsible for this improvement in performance (Fig 6). Similar problems were assigned in the past, but these were worked on paper without immediate formative feedback.

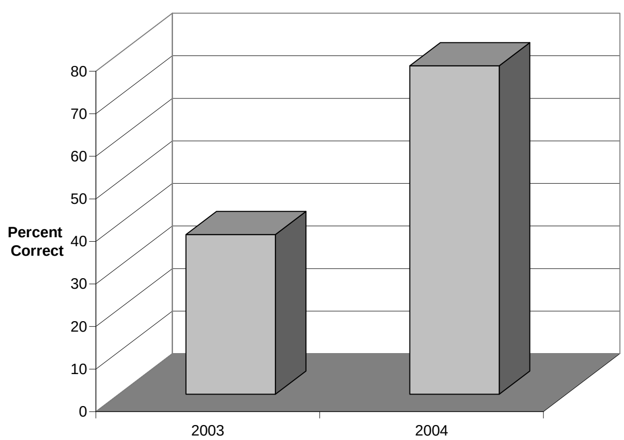


Figure 5 Student performance on a sign/subscript convention question on final exams in 2003 (CAPE module in Fig 5a not used) and 2004 (CAPE module used).

Effectiveness of the online vector tutorial presentation was assessed by comparing pretest and posttest results from 33 students. Students made statistically significant gains ($p<.05$) on five of the six questions (Figure 7). In the next course offering (Spring 2004) the pretest and posttest were both provided via CAPE and eLMS, and the tutorial was available for use by the students throughout the semester. The tutorial has allowed us to reduce the class time needed to review vector operations from 2-3 class sessions to none.

Discussion

Formative assessment is a major factor that contributes to the effectiveness of the "How People Learn" framework.[1,7] Formative assessment is largely lacking in the traditional approach to engineering education, but is strongly emphasized in our online modules. We have implemented formative assessments both in the classroom with PRS to monitor students' conceptual understanding, and out of class with CAPE/eLMS assessment granules that provide practice with feedback on fundamental problems and procedures like vector operations and free body diagram construction.

How can we help students make better use of the time they spend on course-related activities conducted outside of the classroom? Traditional engineering homework consisting of weekly problem sets can be very inefficient and ineffective. They are inefficient because teaching assistants or instructors spend a great deal of time grading the assignments, most of which are correct. Problem sets are often ineffective because students do not receive them back in a timely fashion and comments written on the papers are usually minimal or difficult to interpret. Such feedback is far from being formative. Online homework, assigned after each class, rather than weekly, can potentially eliminate all of these difficulties. Students can receive immediate feedback, can be provided with remediation, and can receive their grade immediately. Furthermore, the time formerly spent grading homework could be devoted to helping those students who had difficulty with the assignment. We have implemented such a system using CAPE and eLMS, and the results thus far are quite encouraging. We will continue our efforts to construct even more sophisticated interactions that require more problem solving and analysis skills in addition to the procedural skills associated with developing expertise.

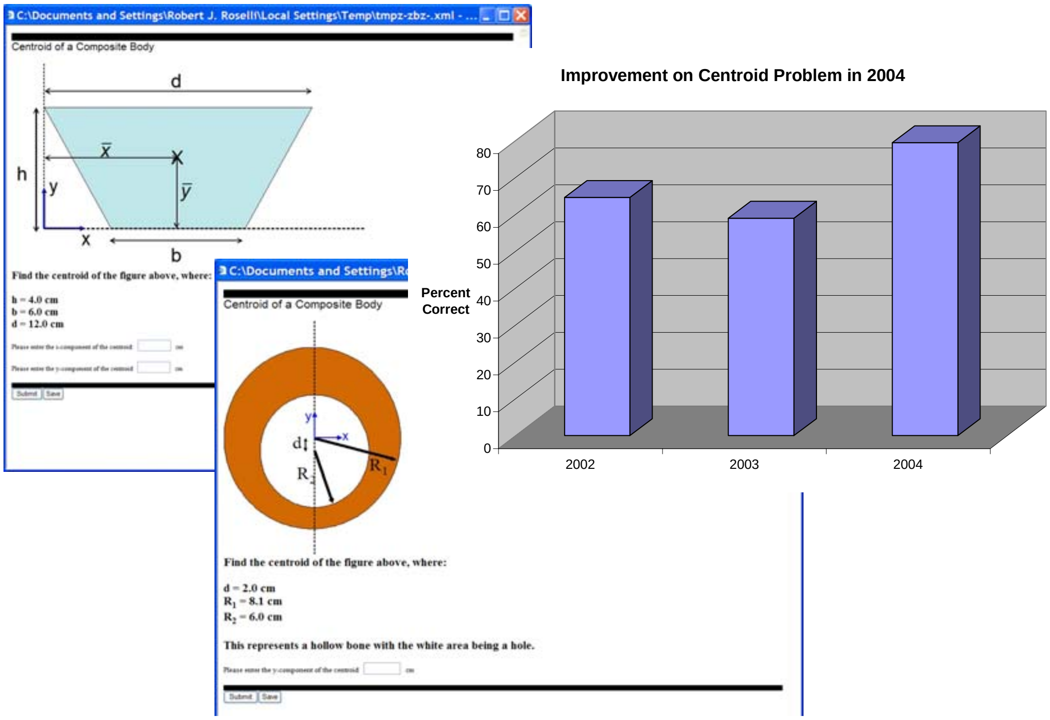


Figure 6. Two centroid problems introduced in 2004 and their influence on student performance on a centroid problem on the final examination in 2004.

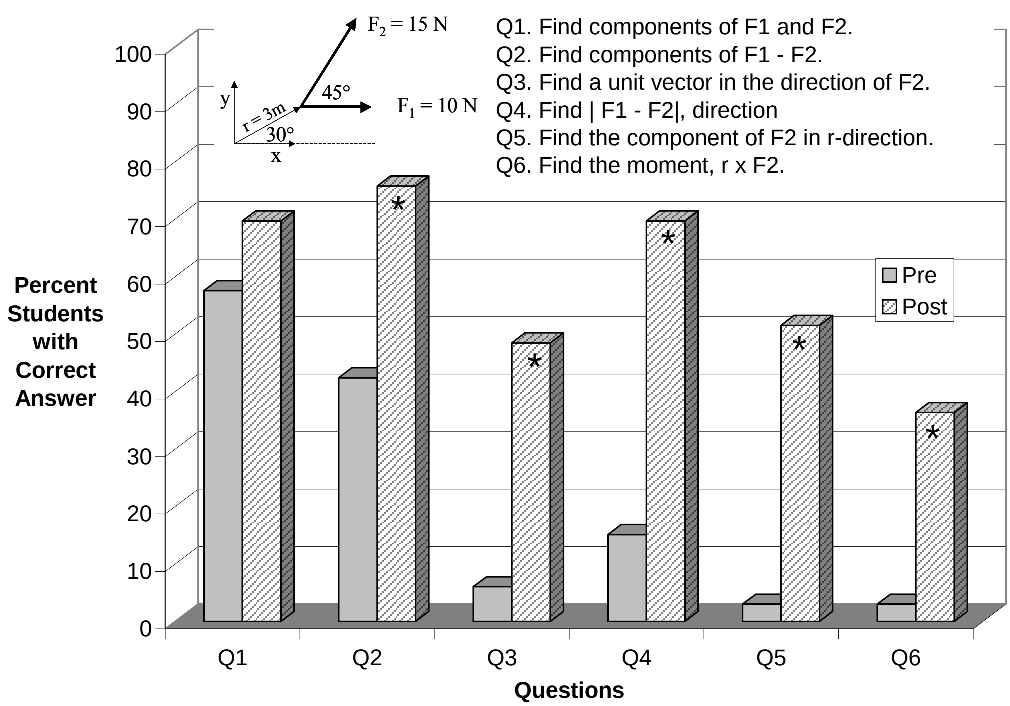


Figure 7.Student performance on six vector-related questions before and after viewing a vector tutorial and completing a CAPE module on vector addition. Ordinate shows the number of students out of 33 with the correct response. Asterisk indicates the posttest score was significantly better than the pretest score using a paired t-test (p<.05).

Our experience with constructing design patterns in CAPE over the past two years has shown that quantitative engineering problems in many different fields can be modeled with a relatively small number of modeling patterns [2]. The appropriate pattern depends upon the number of answers that must be provided by the student, the extent of feedback, and the number of intermediate steps necessary to arrive at the final answers. To make the design of online problems easier, we are in the process of constructing templates that capture the invariant features of CAPE instructional design patterns and are developing a form-based method for introducing problem-specific data.

In summary, the types of online homework assignments described in this paper can provide significant benefits to the student. Remediation steps in online assignments provide automated formative assessment. Remediation is individualized and can be progressive and dynamic. Students can gain assisted practice in applying difficult concepts. Good students will spend less time with the system, while poor students will get the remediation that they need. Since grading is automated, students know their homework score immediately after completing the assignment. Students generally like the system and in polls conducted in two classes preferred to submit their homework online rather than submit paper copies. They particularly liked the ability to review the homework, either by themselves or with the instructor or TA.

Instructors, too, will find many benefits in assigning online problems with feedback. Input variables can be randomized so that each student works on a different numerical problem. Less class time can be spent covering some of the more difficult concepts if the students have an opportunity to apply them in online assignments containing feedback. No class time is spent in collecting or passing back homework assignments and the homework deadline is automatically enforced. The instructor effort in preparing homework will initially be greater than in the past, but this should decline with time. In reviewing homework with students, many misconceptions are uncovered and these can be used by the instructor to expand the remediation pathways in the module. Finally, a significant benefit is that the TA effort is redirected from grading to assisting students who most need the help.

Acknowledgements

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