

Games as Teaching Tools in Engineering Mechanics Courses

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Abstract

The computer as a teaching medium affords new opportunities for creative instructional activities that are not possible in the traditional lecture and textbook format. One such type of activity is the use of interactive games. Several games have been developed and implemented in the Statics and Mechanics of Materials courses at the University of Missouri – Rolla. These games focus on fundamental topics such as centroids, moments of inertia, shear force and bending moment diagrams, the first moment of area Q , and Mohr's Circle for plane stress. These games seek to develop the student's proficiency and confidence in narrowly defined but essential topic areas using repetition and carefully constructed levels of difficulty. The game format provides students with a learning structure and an incentive to develop their skills at their own pace in a non-judgmental but competitive and often fun environment. Performance improvements and student reaction to the games are discussed.

I. Introduction

Engineering mechanics courses such as Statics and Mechanics of Materials are courses that seek to develop the student's ability to analyze basic engineering machines, mechanisms, and structures and to determine the information necessary to properly design these configurations. Fundamental calculations such as centroids, moments of inertia, shear force and bending moment diagrams, and Mohr's circle transformations are building blocks that students must employ to solve problems and develop designs in a variety of situations. Accordingly, the likelihood of a student's success in engineering mechanics courses is enhanced if they master these fundamentals.

It is often assumed that repetition leads to proficiency; however, few students relish working dozens of problems on a particular topic. To make the learning process more enjoyable, repetition and drill on a specific topic can be encapsulated in a game context. Through the challenge of the game, the student can receive the benefits of repetition without the sense of labor that they might feel otherwise. A game context provides students with a structure for learning and permits students to develop their skills at their own pace in a non-judgmental but competitive and often fun environment. Since the computer is a medium that is well suited for repetitive processes and for numeric calculations, computer-based games focused on specific calculation processes offer great potential as a new (or perhaps updated) type of learning tool for engineering mechanics courses.

At the University of Missouri – Rolla, several computer-based games have been developed to supplement the Statics and Mechanics of Materials courses. These games focus on narrowly defined topic areas with the intent of helping students develop proficiency in basic calculations. In this paper, games targeted on three fundamental calculation skills – centroids, the first

moment of area Q , and Mohr's circle transformations for plane stress – are described, and student response to these games is discussed.

II. *The Centroids Game*

In the Statics course, students learn how to compute the centroid of a composite cross-sectional area. To help students improve their proficiency in centroid calculations, *The Centroids Game* was developed. This game is constructed in two parts, each with multiple levels (termed rounds), designed to lead the student from recognition of a proper calculation to the ability to correctly perform the calculation.

The first part of the game, called *The Centroids Game – Learning the Ropes* (Figure 1), consists of six rounds. In round 1 (Figure 1a), the student is presented with a series of shapes comprised of rectangles. A target centroidal axis is superimposed on each shape in an incorrect location. The student is asked to decide whether the true centroidal location is above or below this axis. The purpose of this round is to try to develop a student's intuitive understanding of centroids so that they develop a sense of where the centroid should be located before they begin the calculation, rather than performing a calculation and blindly accepting whatever number they obtain. For each question in the round, students receive immediate feedback whether they answer correctly or incorrectly, and points are awarded for correct answers. After responding to all shapes in round 1, students are shown a scorecard that indicates the points scored and the possible points in the round. At this juncture, a student may elect to repeat round 1 to improve their score. If they do repeat the round, the game randomly shuffles the target centroidal axes so that the student sees a slightly different problem. The student may elect to repeat the round as many times as they wish before moving on to round 2.

For round 2, a centroid calculation presented in a tabular format is shown for a shape (Figure 1b). One of the terms in the calculation table is purposefully made incorrect, and the student is asked to identify the incorrect term. The student receives full points if they identify the incorrect term on the first attempt, but the available points are successively reduced for each unsuccessful attempt. A student could opt to randomly guess, but the odds of gaining full points for each question are not favorable. After completing round 2, the scoreboard is again shown and the student is given the chance to repeat the round. The student may repeat only the most recent round; therefore, a student could not opt to repeat round 1 at this point. If the student elects to repeat the round, the questions are again randomly shuffled, and thus, students will encounter a slightly different problem each time they repeat the round.

For round 3, a centroid calculation is presented in a tabular format; however, one area term and one distance term are left blank (Figure 1c). In round 4, all of the distance terms are omitted (Figure 1d), and in round 5, all of the terms are left blank (Figure 1e). In each of these rounds, the student receives points for each correct term that they enter. The points awarded increases with each round. The game provides feedback immediately after the student submits an answer. At the close of each round, the student is allowed to repeat the round with the problems randomly shuffled for each attempt.

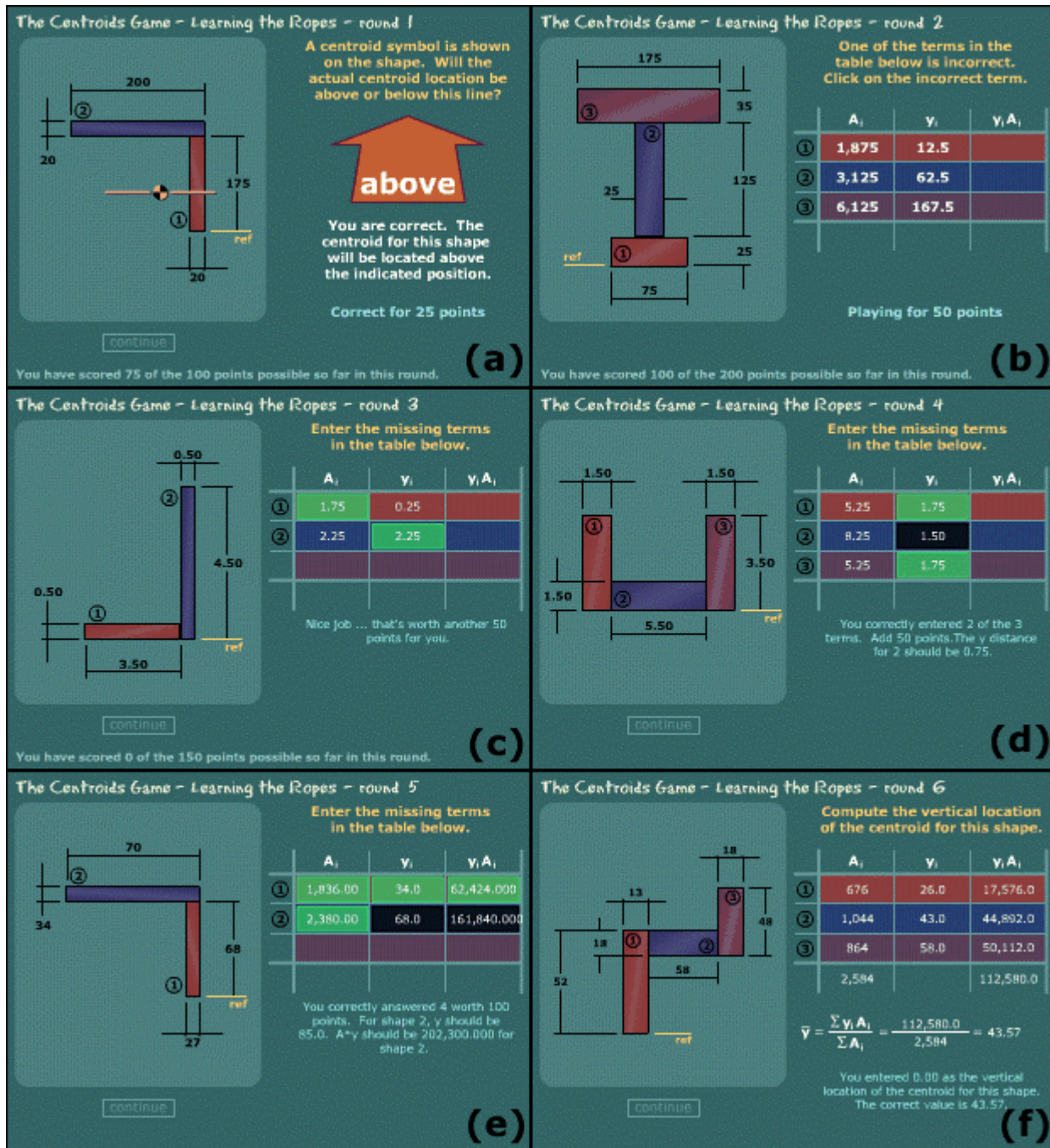


Figure 1. The Centroids Game – Learning the Ropes

In the final round, the student is presented with a single dimensional shape but no other information. The student is asked to compute the correct centroid for the shape (Figure 1f). After submitting an answer, the student is shown the correct calculation. The possible point total for this last question is set very high so that the student cannot get a good score for the entire game unless they successfully answer the round 6 question.

The second part of the game, called *The Centroids Game – Master of the Realm*, continues the same game format. The Master of the Realm game (Figure 2) features composite bodies made up of rectangles, triangles, semi-circles, and circles, including holes having these shapes.

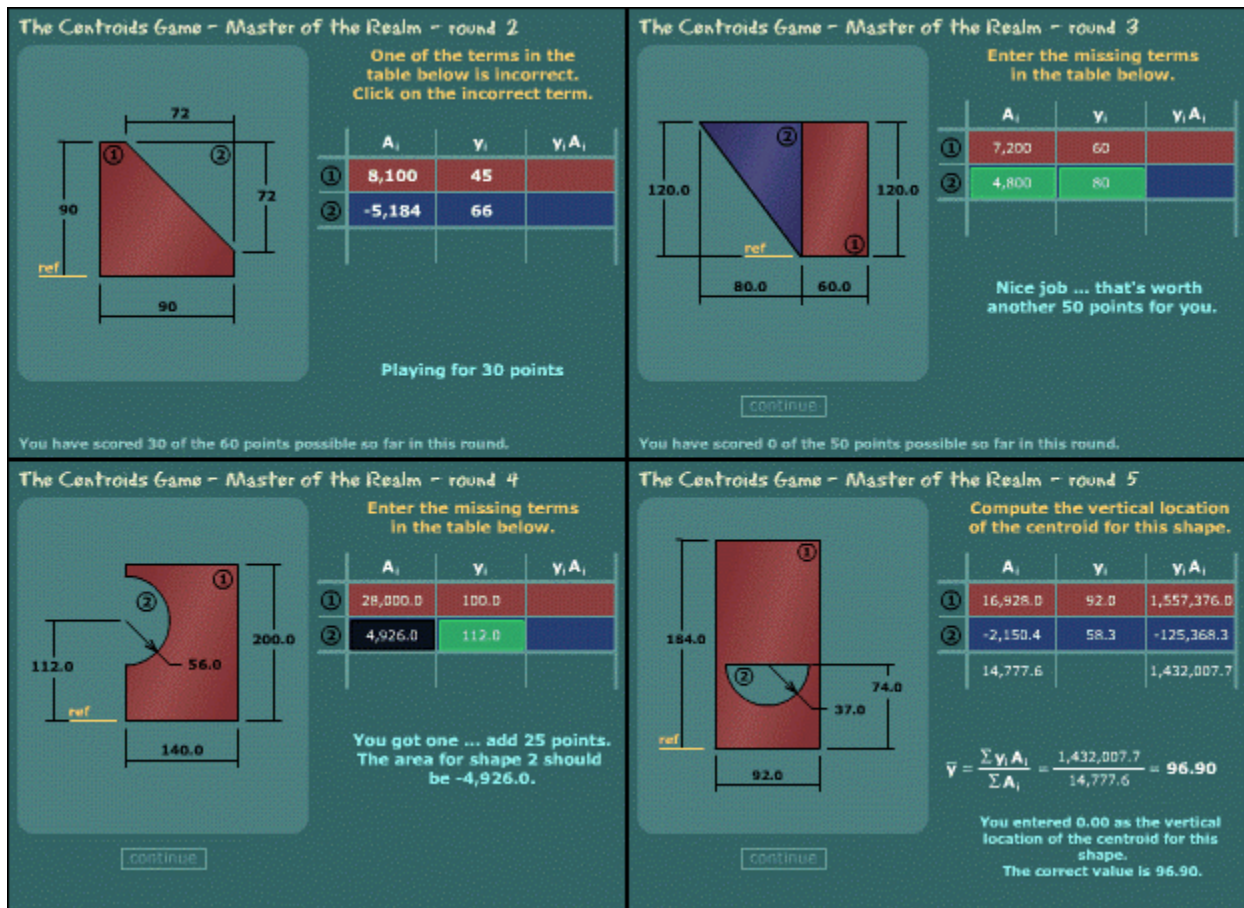


Figure 2. *The Centroids Game – Master of the Realm*

III. Q-tile – The Q Section Property Game

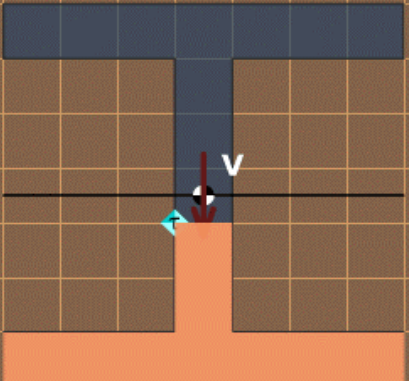
In Mechanics of Materials, the transverse-shear-stress developed in flexural members is computed from the equation:

$$\tau = \frac{VQ}{It}$$

Calculation of the proper value of Q, the first moment of a portion of the cross-sectional area about the centroidal axis, for use in this equation is often troublesome for students. Examination of student solutions to exam and homework problems reveals that one of the most common errors in calculating Q is incorrect identification of the area. Based on this observation, a game called *Q-tile* (Figure 3) was developed with two objectives in mind:

Q-tile The Q Section Property Game
round two

Transverse shear stress t due to the indicated shear force V is to be calculated at the point in the cross section identified by this symbol:



When you've finished selecting the appropriate area for the Q calculation, click done.

Sweet...now you're on a roll.

$Q = 192,000 \text{ mm}^3$

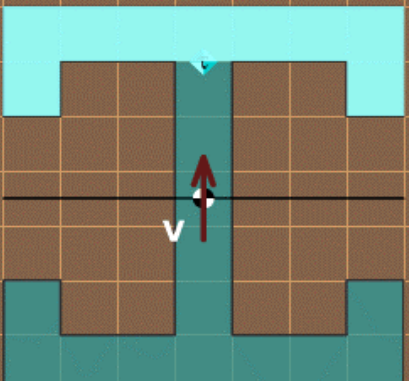
$t = 20 \text{ mm}$

(a)

each tile is 20 mm x 20 mm
add 90 points

Q-tile The Q Section Property Game
round four

Transverse shear stress t due to the indicated shear force V is to be calculated at the point in the cross section identified by this symbol:



Select the proper area needed to calculate Q and click done. You've got 5 seconds to mark the area. Watch out for the bombs!

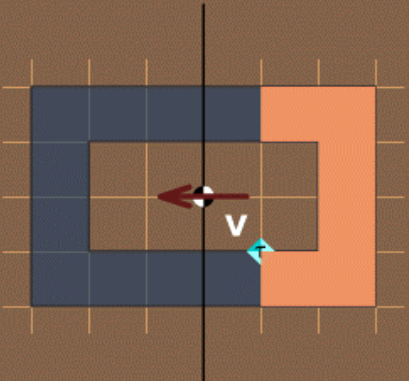
Time's up! Too bad...no points for this one. Here's the correct area needed for the Q calculation.

(b)

each tile is 50 mm x 50 mm
add 0 points

Q-tile The Q Section Property Game
round five

Transverse shear stress t due to the indicated shear force V is to be calculated at the point in the cross section identified by this symbol:



After selecting the proper area, calculate Q and t based on the grid spacing noted below. After entering your values for Q and t, click done.

$Q = 13000$ ✓

$t = 20$ ✓

Absolutely correct! Well done!!

$Q = 13,000 \text{ mm}^3$

$t = 20 \text{ mm}$

(c)

each tile is 10 mm x 10 mm
add 360 points

Figure 3. Q-tile – The Q Section Property Game

1. Foster proficiency in identifying the proper area needed for the Q calculation through exposure to a wide variety of cross sections.
2. Strengthen the student's confidence in their understanding of this topic.

In this game, the student is shown a cross section drawn on a grid of squares. The direction of the transverse shear force is indicated. A target is superimposed on the cross section, marking the location where the transverse-shear-stress is to be calculated. The student must select the proper area needed to perform the Q calculation using mouse clicks on the grid squares. In the first two rounds (Figure 3a), the student must simply mark the correct area. The shapes and target locations are randomly varied each time the round is executed. In the 3rd and 4th rounds (Figure 3b), a time challenge is introduced: students are given only five seconds to mark the correct area. The score awarded for each shape is dependent upon how quickly the student completes the selection. To add additional interest, a number of cartoon "bombs" are hidden in the grid. If the student should click on a square containing a bomb, the student receives no credit for the shape. If the student fails to correctly identify the necessary area in the allotted time, the game highlights the correct area. In the 5th and final round of the game (Figure 3c), the student must identify the proper area and then compute Q and t values for seven typical shapes.

The Q-tile Game focuses primarily on identification of required areas, a prerequisite step in correctly performing the calculation of Q. Since the game involves mostly mouse clicks on grid squares, the student can be quickly confronted with a wide variety of cross sections for consideration – many more shapes than they will likely face during their entire study of shear stresses in beams. Q-tile's narrow focus and immediate feedback combined with the repetition inherent in the game help to develop the student's (a) proficiency in this fundamental skill, and equally as important, (b) confidence in their understanding. To score well in Q-tile, the student must demonstrate the ability to correctly identify the proper area for Q and successfully perform the Q calculation.

IV. *The Mohr's Circle Game*

One of the first steps in learning how to use Mohr's circle is the ability to recognize a correctly drawn Mohr's circle. *The Mohr's Circle Game* focuses on this fundamental skill. Scenes from *The Mohr's Circle Game* are shown in Figures 4 through 6. The objective of this game is to develop the student's ability to recognize a correctly drawn Mohr's circle. From this foundation of understanding, the student can proceed to develop proficiency in constructing and interpreting Mohr's circle for plane stress.

Figure 4 shows *The Mohr's Circle Game*. In round 1 of this game, the student is shown a stress element and three Mohr's circles. The student clicks on the Mohr's circle that corresponds to the given stress element. If the student selects the correct circle, they score 30 points. If the student clicks on an incorrect circle, the game indicates the reason the chosen circle is incorrect (Figure 5). The student can then make another selection, scoring 10 points for a correct answer or no points for an incorrect answer. After solving five stress elements, the game proceeds to round 2 in which the student is shown a Mohr's circle and three possible stress elements (Figure 6).

Round 2 also consists of five Mohr's circle cases. The student clicks on the stress element that corresponds to the given Mohr's circle. If an incorrect stress element is chosen, the game briefly

explains why the choice was incorrect. The game then moves to round 3, which is similar to round 1 except that the errors in the incorrect Mohr's circles are less obvious. After three rounds are completed, the student is given a report that can be printed out and turned in.

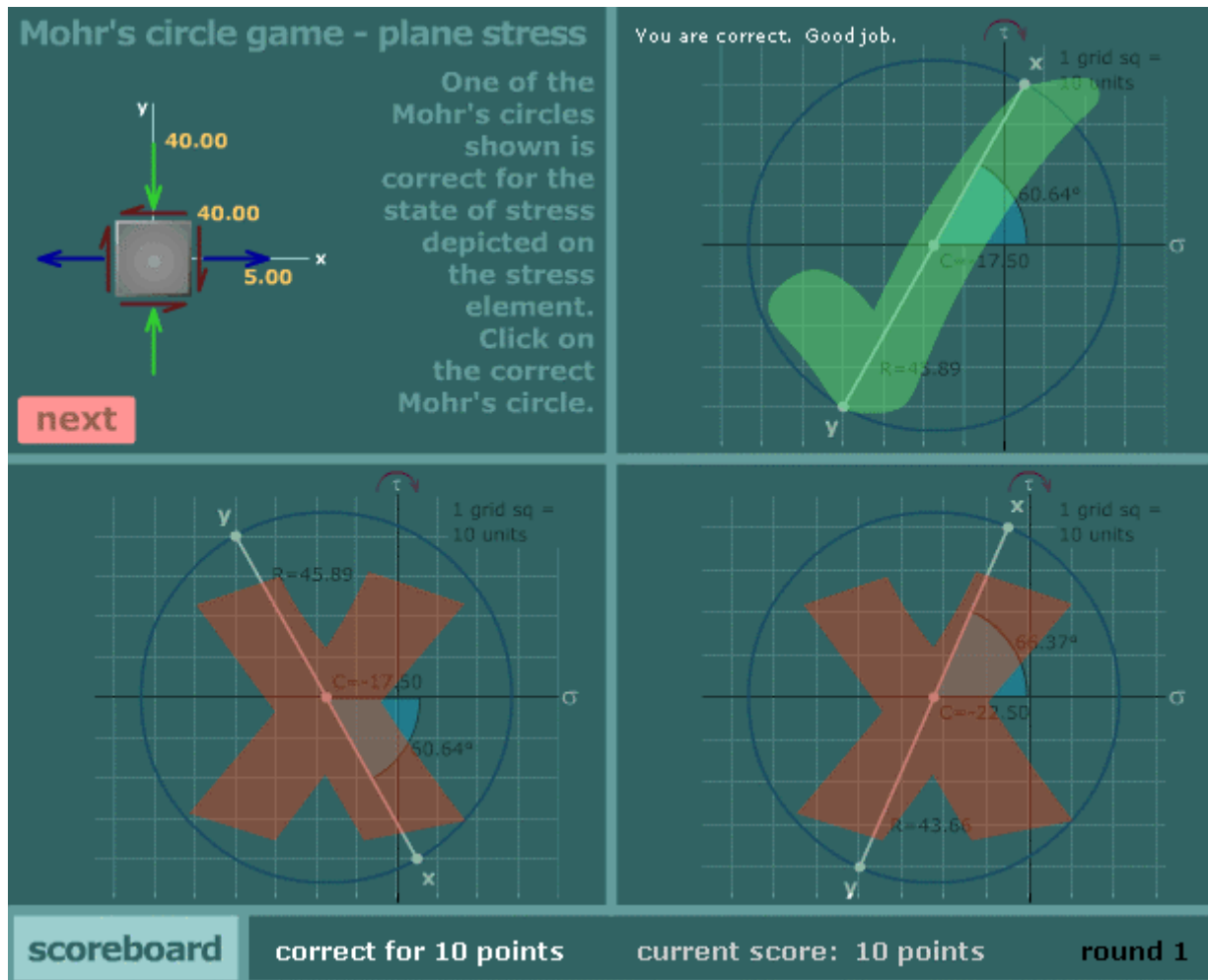


Figure 4. *The Mohr's Circle Game – round 1*

The Mohr's Circle Game is intended as an introductory exercise. This game seeks to strengthen the student's recognition and comprehension of the Mohr's circle. It strengthens the student's ability to apply the fundamental concepts and to become proficient in solving problems of this type.

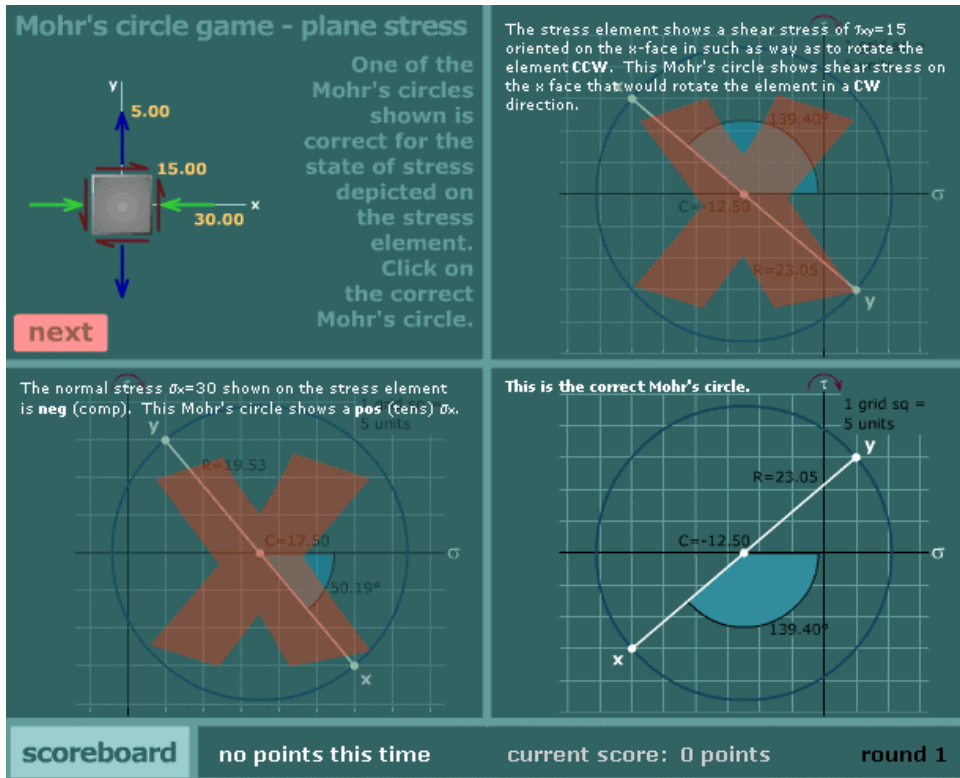


Figure 5. *The Mohr's Circle Game* – response to incorrect selection – round 1

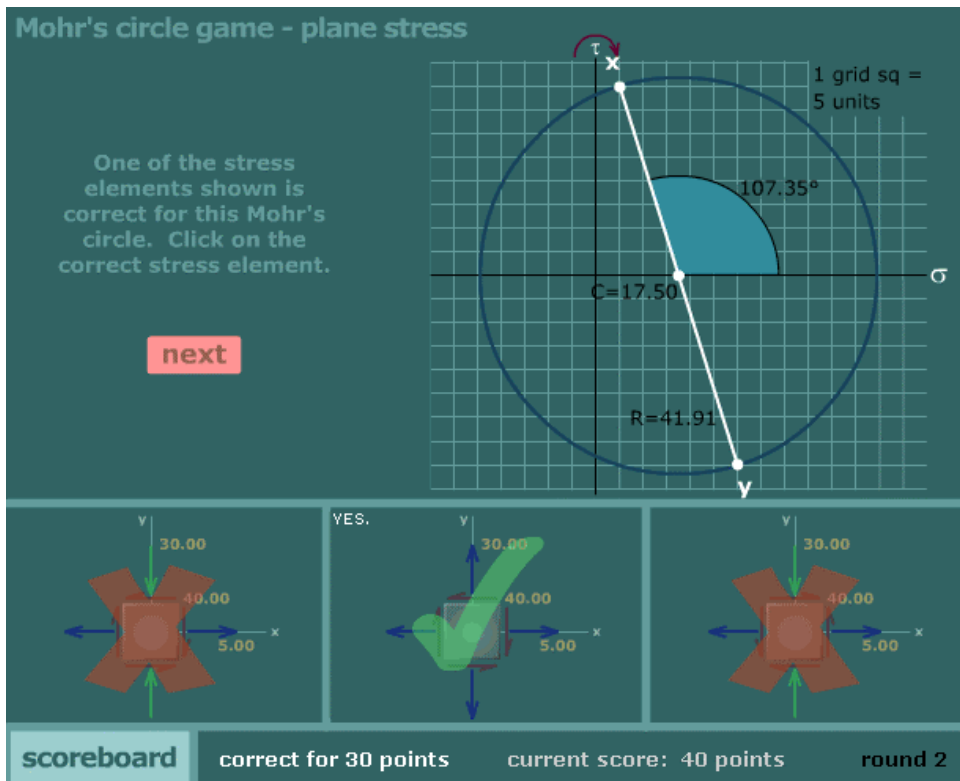


Figure 6. *The Mohr's Circle Game* – round 2

V. Evaluation of *The Centroids Game – Learning the Ropes*

In the Fall 2002 semester, *The Centroids Game – Learning the Ropes* was tested on two undergraduate classes at the University of Missouri – Rolla: one section of Statics and one section of Mechanics of Materials. The evaluation was repeated in the Spring 2003 semester for one section of Statics. Students in the Statics classes were asked to play the game during the regular class period, immediately after the procedure for calculating centroids in composite bodies was briefly discussed. For students taking the Statics course, *The Centroids Game* was used as a teaching tool. *The Centroids Game* was assigned as homework for students in the Mechanics of Materials class. Since these students should be competent in the centroid calculation procedure (Statics with a minimum “C” grade is a prerequisite for the course), *The Centroids Game* was used as a review exercise.

Students in both classes responded to the following statements using a 9 point scale with 1 = “strongly disagree” and 9 = “strongly agree”.

1. After using *The Centroids Game*, I felt confident in my ability to calculate Centroids for composite bodies.
2. After using *The Centroids Game*, I was able to visualize the procedure for calculating Centroids.
3. After using *The Centroids Game*, I understood which cross-sectional dimensions to include in my calculations when working a Centroids problem.
4. *The Centroids Game* helped me to recognize how much I know and don’t know about the procedure for calculating Centroids.
5. I found *The Centroids Game* to be motivational concerning the procedure for calculating Centroids.
6. I liked playing a game to help me get better at calculating Centroids.
7. I learned a great deal about the procedure for calculating Centroids from *The Centroids Game*.
8. I thought the time spent playing *The Centroids Game* was a worthwhile use of my study time.
9. The procedure for playing *The Centroids Game* was easy to understand.
10. The number of questions and the number of rounds used in *The Centroids Game* seemed about right to me.
11. Give your overall evaluation of *The Centroids Game* on the procedure for calculating Centroids, using the 1...9 scale, with 1 being very poor and 9 being outstanding.

The survey results for both the Statics class and the Mechanics of Materials class are summarized in Table 1. Mean values for responses to each of the survey questions listed above are shown in the table. These results show uniformly strong agreement with the survey statements for all classes, indicating that students felt that *The Centroids Game* was helpful, both in clarifying procedures used in centroid calculations and in fostering calculation proficiency. They also enjoyed playing the game and felt that *The Centroids Game* was a worthwhile use of their study time.

<i>The Centroids Game Survey Data</i> (Scale: 1 = strongly disagree, 9 = strongly agree)	Fall 2002 Statics class (n = 27)	Spring 2003 Statics class (n = 23)	Mechanics of Materials class (n = 24)
1. Confidence in ability to calculate centroids	8.00	8.61	8.63
2. Visualization of calculation procedure	8.50	8.35	8.79
3. Understanding of necessary cross-sectional dimensions	8.38	8.13	8.67
4. Recognize how much I know and don't know	7.96	7.30	7.96
5. Motivation	7.75	7.39	8.13
6. I liked playing a game	8.21	8.04	7.67
7. I learned a great deal about procedure	7.75	7.35	6.71
8. Worthwhile use of study time	7.83	7.52	7.83
9. Game procedure was easy to understand	8.58	8.70	8.96
10. Number of game questions about right	7.92	7.70	7.46
11. Overall evaluation of game	8.38	8.04	8.13

Table 1 – Survey Data for *The Centroids Game*

To compare the effectiveness of the game as a teaching tool versus a review tool, responses from the two Statics sections were compared with the Mechanics of Materials section. In comparing responses between Statics and Mechanics of Materials students, mean responses to two of the statements were statistically significant (i.e., the probability of occurring by chance is less than 5%). (Between subjects' t-tests were used to assess statistical significance.) Mechanics of Materials students gave significantly higher ratings for the statement pertaining to their understanding of which cross-sectional dimensions to include (statement 3), and the statement pertaining to understanding the game procedure (statement 9). Both of these results could be anticipated since *The Centroids Game* was a review of the topic for the Mechanics of Materials students while centroid calculations were being learned for the first time by the Statics students. In addition, two comparisons were marginally statistically significant (i.e., the probability of occurring by chance is less than 10%). The Statics students rated their liking for the game substantially higher (statement 6), and Mechanics of Materials students gave a substantially higher rating with regard to the amount they learned about the procedure for calculating centroids (statement 7). It is important to note, however, that all mean ratings were very high (keep in mind that this is a 9 point scale, with 9 representing strong agreement).

To assess the effectiveness of *The Centroids Game* in a remedial role, students in the Mechanics of Materials class responded to three additional statements:

1. Before using *The Centroids Game*, I felt confident in my ability to calculate Centroids for composite bodies.

2. Before using *The Centroids Game*, I was able to visualize the procedure for calculating Centroids.
3. Before using *The Centroids Game*, I understood which cross-sectional dimensions to include in my calculations when working a Centroids problem.

Ratings by the Mechanics of Materials students for the three “before” statements (statements 1, 2, and 3 immediately above) were compared with the corresponding “after” statements (statements 1, 2, and 3 from the initial list). In each case, students rated the “after” item significantly higher. (Within subjects’ t-tests were used to assess the statistical significance.) The differences between before and after responses were statistically significant. For statements 1 and 3, the probability of the difference occurring by chance is less than 0.1%, and for statement 2, the probability of the difference occurring by chance is less than 1%. From this result, one could conclude that *The Centroids Game* was helpful as a review tool for students.

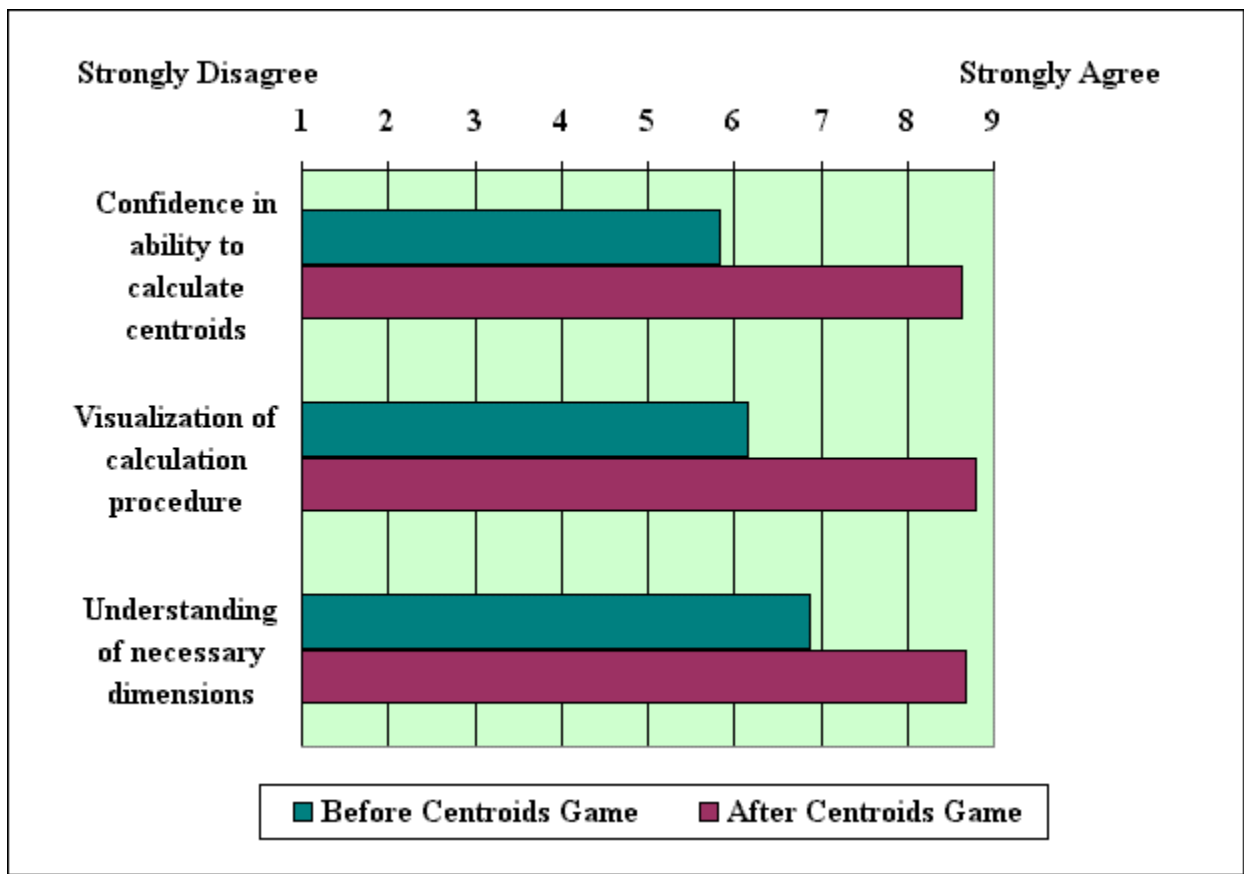
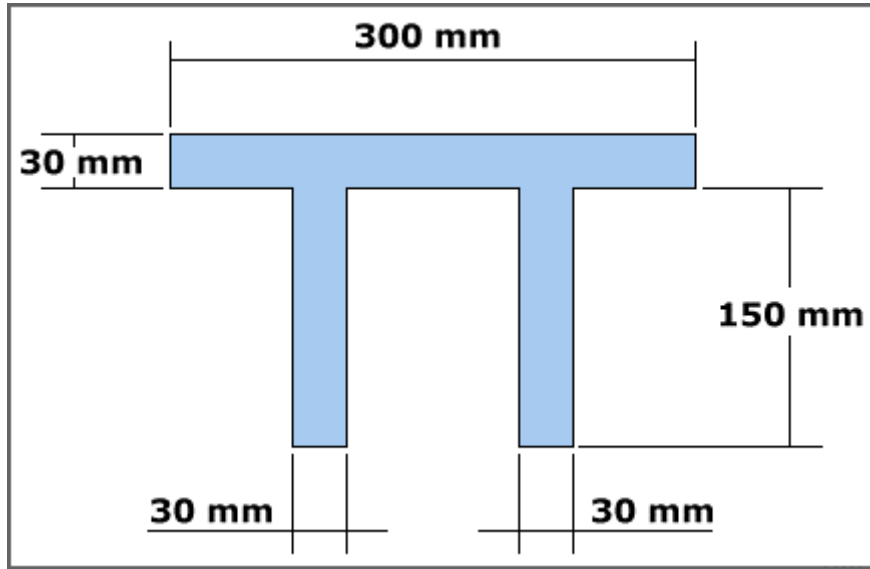


Figure 7. Mechanics of Materials class – Before and After Centroids Game

In the Spring 2003 experiment, a single-problem quiz was administered to students at the end of the class period following completion of *The Centroids Game* exercise. To serve as a control group, students in four additional Statics sections were also given the same quiz. None of these students had exposure to *The Centroids Game*. Students in the control group took the quiz either one class period or two class periods after the topic of centroids of composite areas had been

discussed in lecture. Students in the control group, therefore, had some opportunity to review notes and work assigned homework problems in the days following their in-class exposure to this topic. Students in both the test and control groups, however, were not told about the quiz before the class period in which it was administered.



Compute the location of the centroid in the vertical direction for the shape shown.

Figure 8. Quiz Problem Administered to Statics Sections – Spring 2003

The quiz question is shown in Figure 8. Students were asked to compute the vertical location of the centroid for a double-tee shape. Quizzes were marked correct if the student reported the centroid location as 60 mm from the top or 120 mm from the bottom of the shape. For the purposes of this study, any other response was counted as incorrect. The results of the quiz are shown in Table 2.

<i>The Centroids Game</i> Quiz Results	Total Number of Students Taking Quiz	Correct Responses	Incorrect Responses
Students who played <i>The Centroids Game</i>	23	23	0
Students in control sections	91	55	36

$$X^2(1) = 10.50, p < .01$$

Table 2 – Quiz Results for *The Centroids Game*

An analysis was conducted to compare problem scores for students in the test section with those the control sections. Since these data consisted of dichotomous data, a two-way Chi-Square was computed to test for significant differences between the sections (module vs. control). This test

was statistically significant, indicating that those in the centroids module group performed significantly better on the quiz problem than those in the control group.

VI. Evaluations of *Q-tile* and *The Mohr's Circle Game*

Both *Q-tile* and *The Mohr's Circle Game* have been used in several Mechanics of Materials classes during the past three semesters. The games have been assigned as homework with the stipulation that the student is to play the game until they attain a score of 90% or greater. These assignments preceded significant classroom discussion on the respective topics. Student response to both games has been very positive. Students generally enjoy both games and usually achieve near-perfect scores. Subjectively, the games seem to elicit more questions (and particularly more focused questions) about these topics during subsequent class periods than what would ordinarily be observed without the game assignments. While controlled experiments to directly assess the effectiveness of these two games have not been conducted to date, students seem to learn the proper area needed to calculate Q and the details of Mohr's circle construction more quickly than was typically the case. While this evidence is not rigorous, it does provide some anecdotal support that encourages further pursuits in this area.

VII. Conclusions

Several simple, computer-based games have been developed to help engineering mechanics students develop proficiency and confidence in narrowly defined but essential topic areas. The games use repetition and carefully constructed levels of difficulty to lead students toward improved skills. The game format provides students with a learning structure and an incentive to develop skills at their own pace in a non-judgmental but competitive and often fun environment. Several structured experiments involving the use of these games in engineering mechanics courses have been conducted at the University of Missouri – Rolla during recent semesters. The response to the games has been uniformly positive among both Statics and Mechanics of Materials students. In addition, individual instructors have reported that the games appear to improve student performance in the targeted topic areas. Future research will expand on this study, with particular emphasis on assessing the relationship between student learning and the use of computer-based games.

VIII. Acknowledgement

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Web Address

Materials presented in this paper are available via the Internet at:
http://web.umn.edu/~bestmech/preview_mechmatl.html