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Motion Visualization and Creation of Free-body and Kinetic Diagrams

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An App for Motion Visualization and Creation of Free-body and Kinetic Diagrams of Objects

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Introduction

In order to correctly solve problems in mechanics using the method of first principles, students must be able to extract information from the statement of the problem and visualize the motion. In addition, a free-body diagram that shows the external reactions that caused the motion of the object, and a kinetic diagram that shows the reactions in the resulting motion are essential. If the free-body diagram or kinetic diagram is incorrect the solution of the problem will certainly be incorrect. It has been observed that an error made by the student in any of the aforementioned items may result in the student's inability to solve a problem. The primary motivation for creating the app was to help students visualize the motion of objects that is depicted in the problem statement, and to provide an environment in which they can practice drawing free-body and kinetic diagrams that are needed to analyze the object's motion. The app should be able to do the following:

- Provide an animation that will help the student to visualize the motion. This first step is crucial as it will help eliminate misconceptions or misinterpretations of the motion.
- Help to identify errors in the diagrams due to forces being unaccounted for and provide feedback that leads to success in future attempts at generating the diagrams.
- Give the student multiple attempts to generate the diagrams. However the student's first attempt should be graded and recorded so that the instructor is better able to identify areas or concepts that should be reviewed.
- Provide a password protected environment that will require students to log in to use the app at their convenience throughout the semester.

The Graphical User Interface

In the first phase of the creation of the app, a range of problems that span the kinetics of particles and rigid bodies was selected. The author chose problems that were challenging for most students as illustrated in the scores for homework assignments, quizzes, and exams. The next phase concentrated on the layout of the app. The inclusion of the animation of the problem statement seemed necessary as some students had difficulty identifying the motion of the objects.

The author has been teaching dynamics for over twenty years and in 2000 started to use powerpoint animations to illustrate motion of objects. These animations, though somewhat effective, were only shown during the classroom lectures. It was also time-consuming to create them. In the fall semester of 2014 the author considered involving students in the creation of the animations and researched other programs available to all students in the college of engineering. Civil and mechanical engineering students enrolled in the dynamics course have completed a computer-aided design course such as autocad or Solidworks. Working Model 2D [1] was selected as the adequate software as it builds on the students' CAD skills. The availability of Working Model 2D animations complemented the app. The design of the layout was primarily that of the author with minor suggestions provided by a graduate student assistant [2] in the college of computer science. The graduate student selected Visual Basic as an acceptable software and developed the code. The free-body diagrams, kinetic diagrams, and the feedback that was to be given to the students were created by the author. This app is not commercially available.

The general layout of the app is now discussed. The Free-Body-Diagram App – herein referred to as FBD – has the graphical user interface shown in Figure 1.

Circle 1: Problem Window

This area displays the problem statement. It includes all information needed to solve the problem as well as the information necessary to draw the free body and kinetic diagrams.

Circle 2: Problem Diagram

Each problem comes with an illustration meant to further clarify the problem statement. The user can inspect any diagrams or figures associated with the problem. In addition, the user can either left-click or right-click on this image to bring up the following options:

1. Left-Click
   Enables an animated movie to be played which illustrates the motion of the object. The movie is created with Working Model 2D and exported in .avi format for use by the FBD app.

2. Right-Click
   Zooms in on the diagram or illustration if they happen to be too small to inspect.

Circle 3: FBD Feedback Box

The user can ask to be graded at any time during the process of drawing the free body diagram. The software determines the correctness of the user's free body diagram and provides feedback accordingly. Feedback is given inside this box.

Circle 4: KD Feedback Box

Similar to Circle 3, feedback is given in the Kinetic Diagram (KD) Feedback Box. The user can ask to be graded at any time during the drawing of the kinetic diagram. This textbox provides feedback concerning the correctness of the user's kinetic diagram.

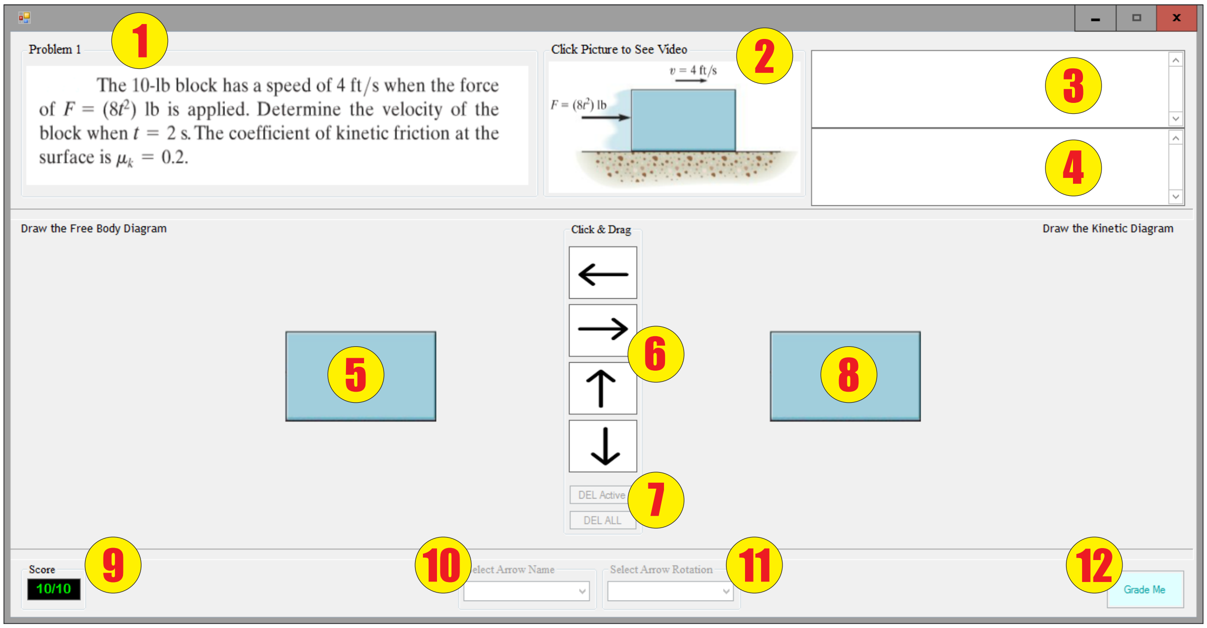


Figure 1. Free-body Diagram App Layout

Circle 5: Free-Body Diagram

This area shows the body isolated from its surroundings and allows the user to superimpose reactions, i.e. arrows and/or torques, selected from the area in CIRCLE 6 on the body.

Circle 6: Draggable Elements

In drawing the free body diagram, the user clicks and drags various arrow elements (and sometimes torque elements) directly onto the free body in Circle 5.

Circle 7: Arrow Delete Buttons

If the user places an external reaction in the wrong location and wishes to make a correction, Circle 7 enables this functionality. There are 2 options:

1. Delete Active
   This option deletes the currently "active" (or selected) reaction.
   When a user drags an arrow onto the body, and then clicks on the arrow, it is highlighted in blue and is considered "active". Non-active arrows are shown in black.

2. Delete ALL
   This option enables the user to delete all elements that were dragged onto the body.

Circle 8: Kinetic Diagram

Similar to Circle 5, this is where the user will place arrows and/or torques in order to satisfy the required reactions on the kinetic diagram.

Circle 9: Score

The FBD app keeps track of the score which the user has achieved for each problem. The scoring system behaves as follows:

1. When the user first encounters a problem, the score reads 10/10. However, this is *not* the actual score for the user. It is simply a marker.
2. The user implements what is assumed to be the solution, then requests that the solution be graded by clicking on CIRCLE 12. If the solution is wrong, then a point is deducted and feedback or a hint is provided that should help in the user's next attempt.
3. The user keeps repeating step 2 until
    a. A correct solution is attained. One point is deducted for each incorrect attempt

    or

    b. All 10 attempts at generating the correct diagrams are exhausted. A score of 0/10 is recorded and the score is locked.

If the user abruptly terminates steps 3a or 3b a score is not recorded.

Circle 10: Select Reaction Name Option

Each arrow or torque that is dragged onto the free-body or kinetic diagram must be labelled with the appropriate name or symbol.

A drop-down listbox expands to give the user a list of labels. The user must choose the correct label.

Circle 11: Select Arrow Rotation

When the user clicks and drags an arrow onto the body, the arrow should be placed at the proper orientation. Circle 11 shows a listbox from which the user can choose the correct orientation.

Rotations of torques are positive in the counter-clockwise direction. Also, rotations of arrows are *not* shown as absolute – they are shown as relative. In other words, if a horizontal left arrow is dragged onto a diagram its orientation is assumed to be 180 degrees counter-clockwise. The selection of a positive 10 degrees rotation will result in the arrow pointing 190 degrees counter-clockwise. Similarly a selection of negative 10 degrees rotation will show the arrow at 170 degrees.

Circle 12: Grading

The user can click the GradeMe button at any time during the drawing of either the free-body diagram or the kinetic diagram. This will provide feedback about the correctness of the user's solution. This feedback will be written in the textboxes shown in Circle 3 and Circle 4, as described earlier.

Arrow Names

The current version of the app does not allow for Unicode characters, subscripts or superscripts within the Select Arrow Name listbox. This means that expressions such as: $\mu_k N$ are represented as mu_subk_N.

Tables 1 and 2 show a list of some of the listbox arrow names and their actual equivalents.

Table 1

Listbox Name	Represents
F_sub_sp	F_{sp}
I_subA_alpha	$I_A\alpha$
I_subB_alpha	$I_B\alpha$
m_alpha_halfL	$m\alpha(\frac{L}{2})$
ma_subBt	ma_{Bt}
m(0.3alpha)	$m(0.3\alpha)$
m_subA_a	$m_A a$

Table 2

Listbox Name	Represents
m_subR_wsq(L/2)	$m_R\omega^2\left(\frac{L}{2}\right)$
m_subR_alpha(L/2)	$m_R\alpha\left(\frac{L}{2}\right)$
m_subS_alpha(L+r)	$m_S\alpha(L+r)$
m_subS_wsq(L+r)	$m_s\omega^2(L+r)$
m_wsq_halfL	$m\omega^2\left(\frac{L}{2}\right)$
mu_subk_N	$\mu_k N$
N_subA	N_A
W_subG	W_G

Student involvement is encouraged in the development of the Working Model 2D animation. In the last few weeks of the semester an optional project is assigned for which students receive extra credit. Fall 2014 was the first semester that this project was assigned. Students were given approximately 10 days to complete the project. Very creative animations were submitted. However, there was no requirement that students show details of how their animations were obtained. As a result, a set of guidelines has evolved since 2014 that required students to include more information. Figure 2 shows the project guidelines for the fall 2015 semester that were posted on Moodle, the colleges Learning Management System (LMS). Students are required to work in two or three-member teams to select any problem in the text for which they would like to create an animation. The requirements are that each team submits (i) a theoretical solution, (ii) detailed steps used to create the model, and (iii) a movie of the animation. Students are encouraged to perform independent research to find out how to use the Working Model 2D program. Since its inception, approximately ninety percent of students have opted to participate in the project; see table 3 and Figures 2 and 3.

Table 3. Enrollment and Participation in Working Model 2D Project

Year-Section	Enrollment	Participation	%Participation
Fa11 2014-03-04	53	53	100%
Spring 2015-02	43	40	93%
Fall 2015 -02	36	33	92%
Spring 2016-02	24	19	79%

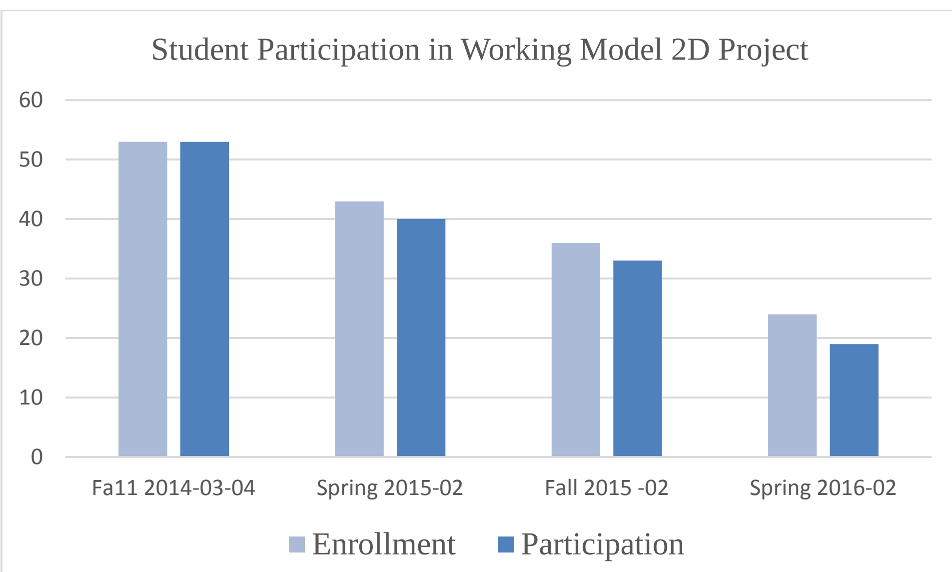


Figure 2 Working Model 2D Student Participation.

Dynamics , ENGR 110-02, Fall 2016

**** Optional Working Model 2D Project (maximum 7% extra credit) ****

Guidelines and Responses to Frequently Asked Questionsns

1. What are the project requirements? **Answer:** To earn 7% extra credit a group MUST submit the following:
   a) A Working Model 2D animation of the system in motion, where the system can comprise of particles or rigid bodies or a combination of both particles and rigid bodies (file submission via Moodle). Problems should be selected from chapters 12, 13, 14, 16, 17 or 18 of the text.
   b) A movie (.avi format) of the animation via VoiceThread.
   c) A detailed documentation of the steps, taken to create the model; use Microsoft WORD or pdf format (via VoiceThread). See the sample online documentation.
   d) A type-written theoretical solution of the problem (submission via Moodle). Hand-written solutions are unacceptable

2. Can we work in groups? **Answer**: Yes; a maximum of 3 group members.

3. How do I select my group members? **Answer:** Select any class member that you wish to work with.

4. Can I work alone? **Answer:** Yes, but you will earn a maximum of 4% unless a group member does NOT fulfill his/her obligations in which case you may earn full credit . Group collaboration is strongly encouraged.

5. How do I know that my problem has not been chosen by someone else? **Answer:** Post your problem number via VoiceThread to the entire class. Priority is given to the first group that selects and submits a problem. Label your selection with the chapter, problem number, and group. Example, Ch18P6Group1 indicates that problem 6 of chapter 18 has been selected by Group 1.

6. Can a group earn partial credit? **Answer:** No. Only acceptable performance is awarded credit. Remember that this project is optional.

7. When is the project due? **Answer:** By 10 pm on 12/06/2016; i.e. Tuesday of the last week of classes.

Late submissions are not allowed.

Figure 3. Fall 2016 Working Model 2D Project Guidelines

Login

Two ways to login to the app are shown in Figure 4.

1. Guest
2. Registered student user

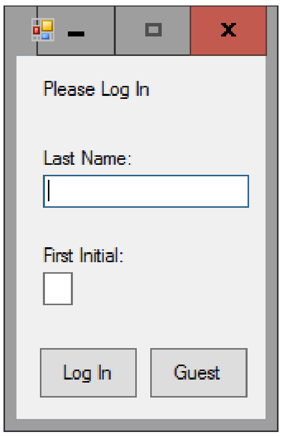


Figure 4. Login Window

A Guest would simply click the Guest button and start using the app.
A student who is registered in the class would enter their last name and first initial in the appropriate boxes before using the app.

As a registered student, the score can be saved for each problem in the app. The app can then track the progress of each student and also display reporting information showing a student's score for each problem.

The registered-student feature is currently built for use by only one instructor.
In order to implement this feature on a general basis for any other instructor's use, further development of the app is required.

Grading

In order to access the Grading screen (applies only to an instructor with registered-student privileges in the app), double click the "problem text" as shown in Figure 5.

Once double-clicked, the Grading window will open which will display a roster of all of the students registered in the class, as well as the scores they have obtained on any given problem. If a score is blank, then that means one of the following conditions apply:

1. The student has not attempted the problem.

2. The student has attempted the problem but has not yet reached the solution or has not yet exhausted the maximum number of attempts (a score of 0 means a student tried ten times and failed to arrive at the solution).

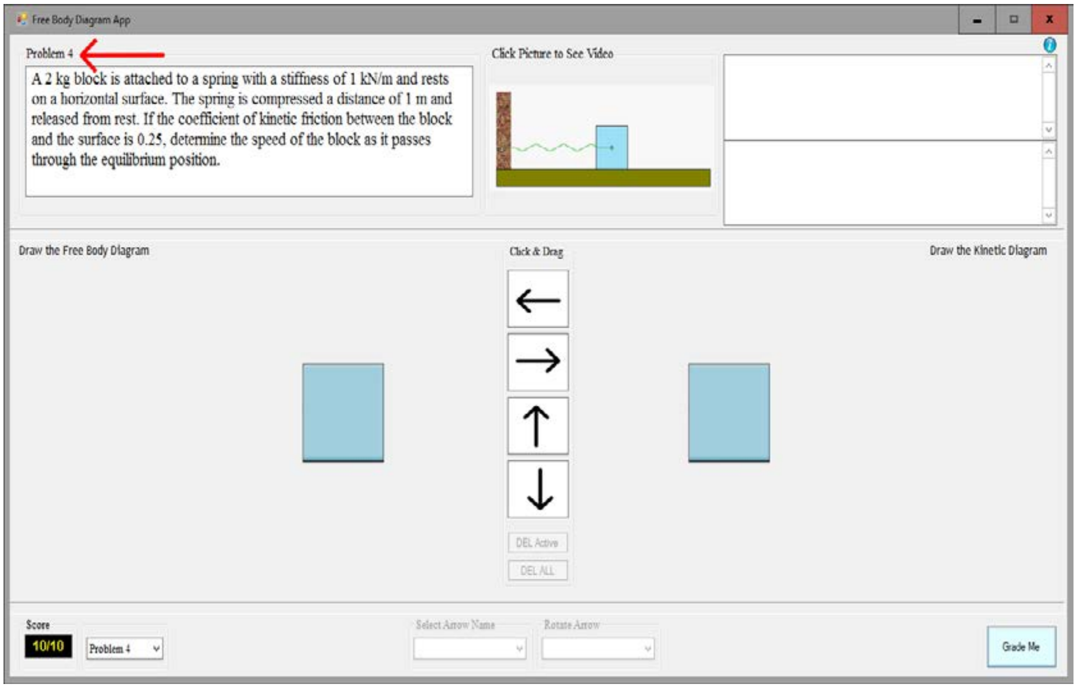
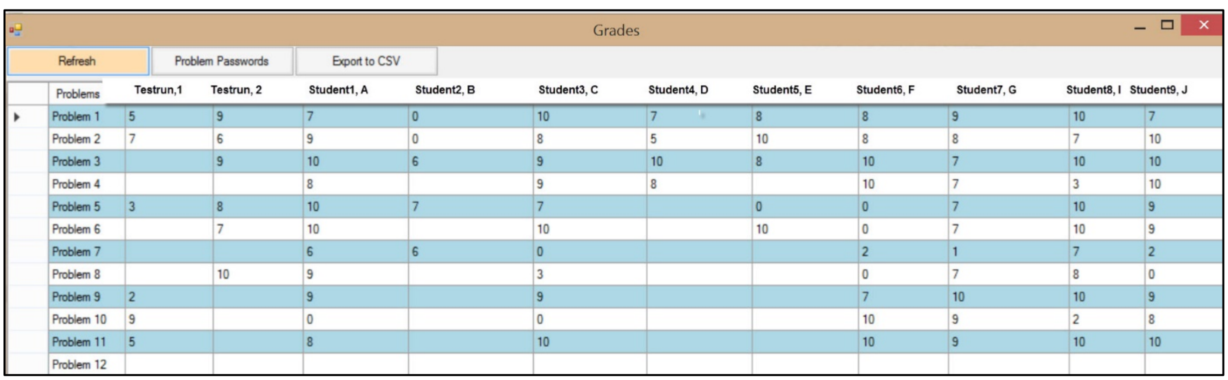


Figure 5. Grading Screen

An illustration of the Grading window is shown in Figure 6.



Problems	Testrun,1	Testrun, 2	Student1, A	Student2, B	Student3, C	Student4, D	Student5, E	Student6, F	Student7, G	Student8, I	Student9, J
Problem 1	5	9	7	0	10	7	8	8	9	10	7
Problem 2	7	6	9	0	8	5	10	8	8	7	10
Problem 3		9	10	6	9	10	8	10	7	10	10
Problem 4			8		9	8		10	7	3	10
Problem 5	3	8	10	7	7		0	0	7	10	9
Problem 6		7	10		10		10	0	7	10	9
Problem 7			6	6	0			2	1	7	2
Problem 8		10	9		3			0	7	8	0
Problem 9	2		9		9			7	10	10	9
Problem 10	9		0		0			10	9	2	8
Problem 11	5		8		10			10	9	10	10
Problem 12											

Figure 6. Grading Window

The grading window shown is a snapshot of the state of the class's performance. As soon as the grade sheet is opened it is updated with the latest scores, refreshing the screen is not necessary. However, if the grading window is opened while a student is completing any of the diagrams then the updated scores will only be recorded after the student has selected the "Grade Me" button. To see the change the instructor must click on the Refresh Button.

Problem Passwords Button

In order to prevent students from accessing problems in topics that have not yet been covered, each problem is password-protected. Each problem has its own unique password. The instructor can retrieve the corresponding passwords by clicking on the Problem Passwords Button.

Export to CSV Button

This button allows the export of grades to a .csv file. The .csv file is created by the app and saved in the instructor's folder on one of the college's servers. The instructor has the option to save the .csv file in a Microsoft Excel format for further processing as needed. For example, the row of student names and affiliated data can be transposed to a column format. At this time the app is not linked to the college's LMS.

A few examples from Hibbeler[3] follow.

Example 1: An illustration of the app used in analyzing a particle in motion

Problem statement: A 40-lb suitcase slides from rest 20 down a smooth ramp. How long does it take to go from point A on the ramp to point C on the ground? Additional details are shown in the app.

The free-body diagram and kinetic diagrams are shown in Figure 7. Upon selecting "Grade me" a hint is given in the top right corner of the app alerting the student that there is an error in the FBD and the score is 9/10.

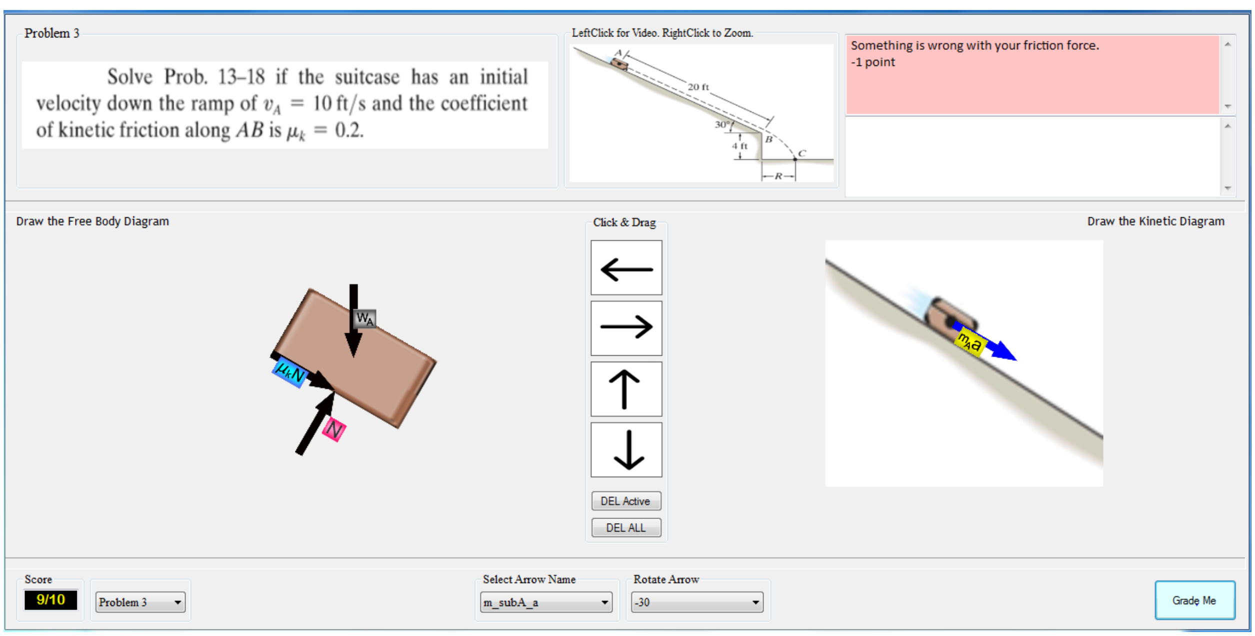


Figure 7. The particle sliding down an inclined surface

The Working Model 2D animation and results are shown in Figure 8. The animation is shown when the link "Leftclick for video" shown in the top center area of Figure 7 is activated.

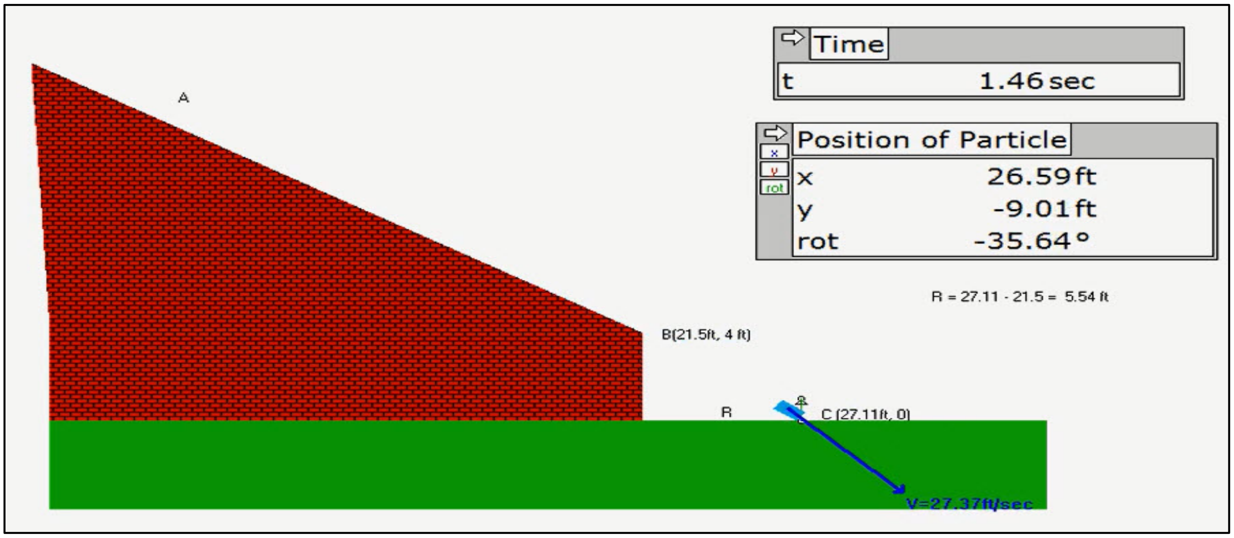


Figure 8. The Working Model 2D animation of the particle showing the results

Example 2: An Illustration Of The App In Analyzing A Rigid Body In Motion

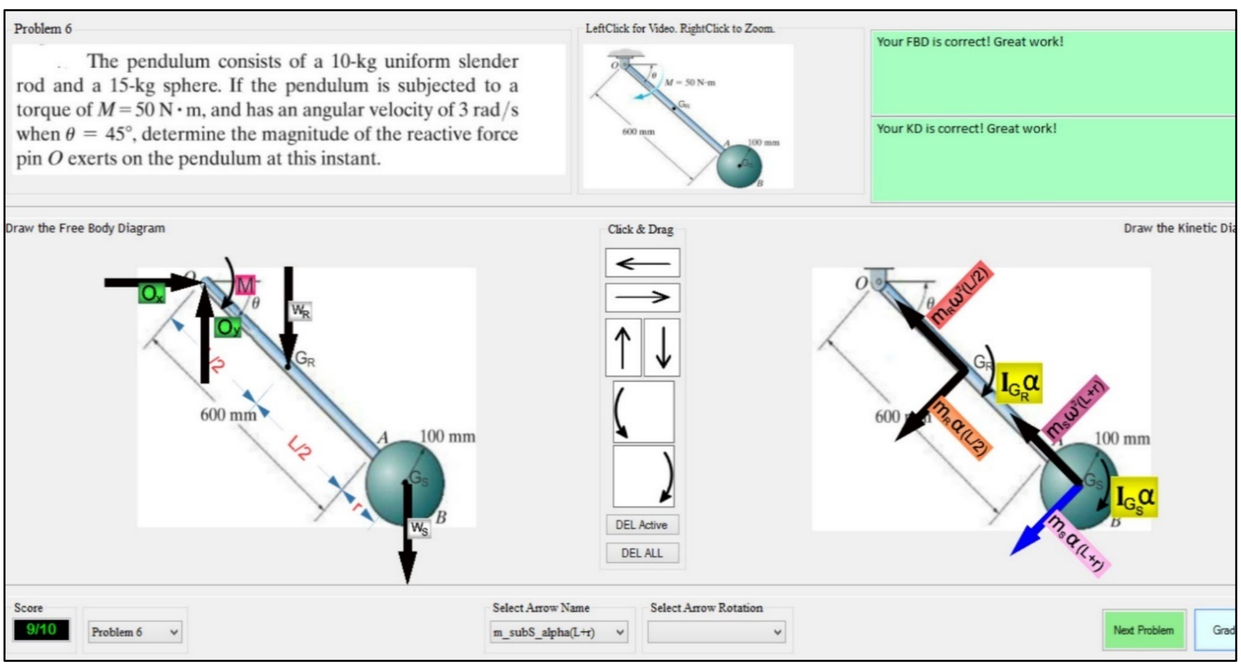


Figure 9. Free-body and Kinetic Diagram

The score of 9/10 in Figure 9 indicates that the student generated the correct diagrams on the second attempt. When the image in the top center area of the app is selected the animation will show the magnitude of the reaction force at pin O as the pendulum swings from the horizontal, see Figure 10. The protractor confirms the angle of rotation in degrees.

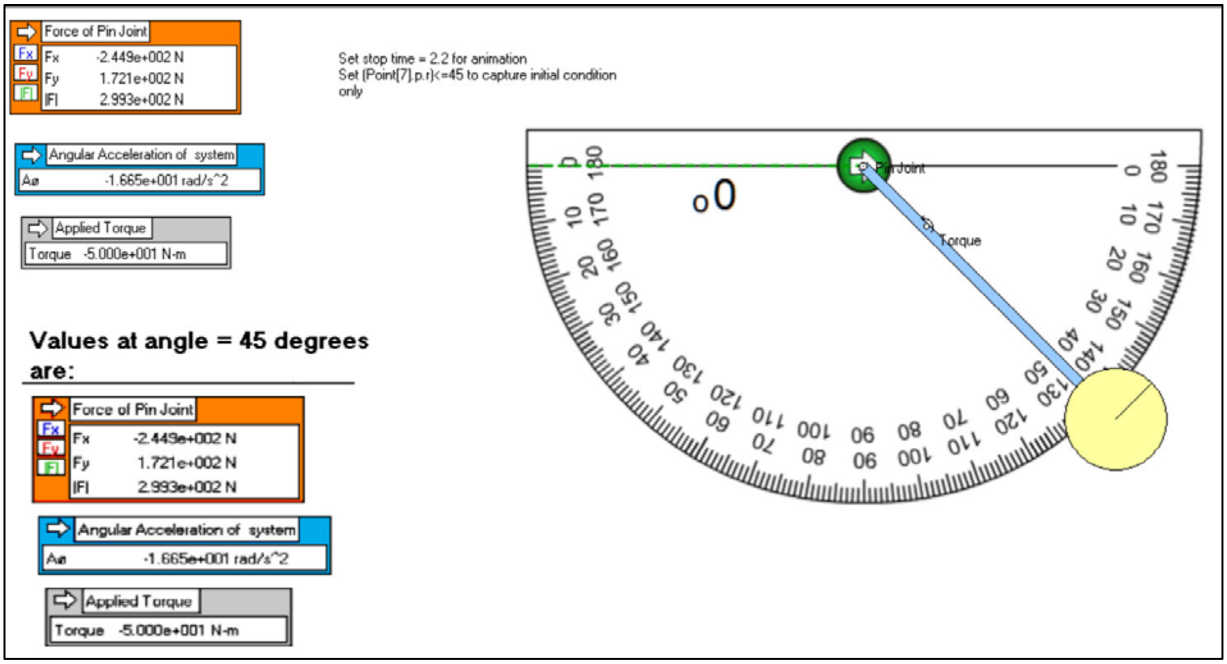


Figure 10. Working Model 2D animation

Example Of Feedback Provided By The App In The Case Of An Error In The Kinetic Diagram

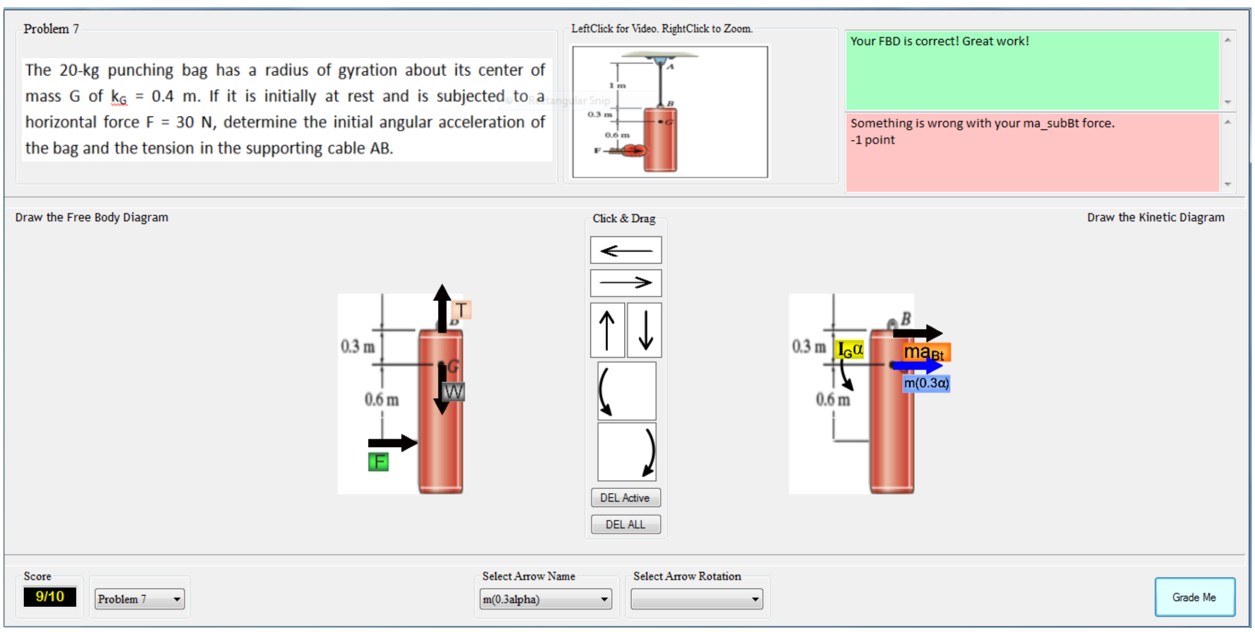
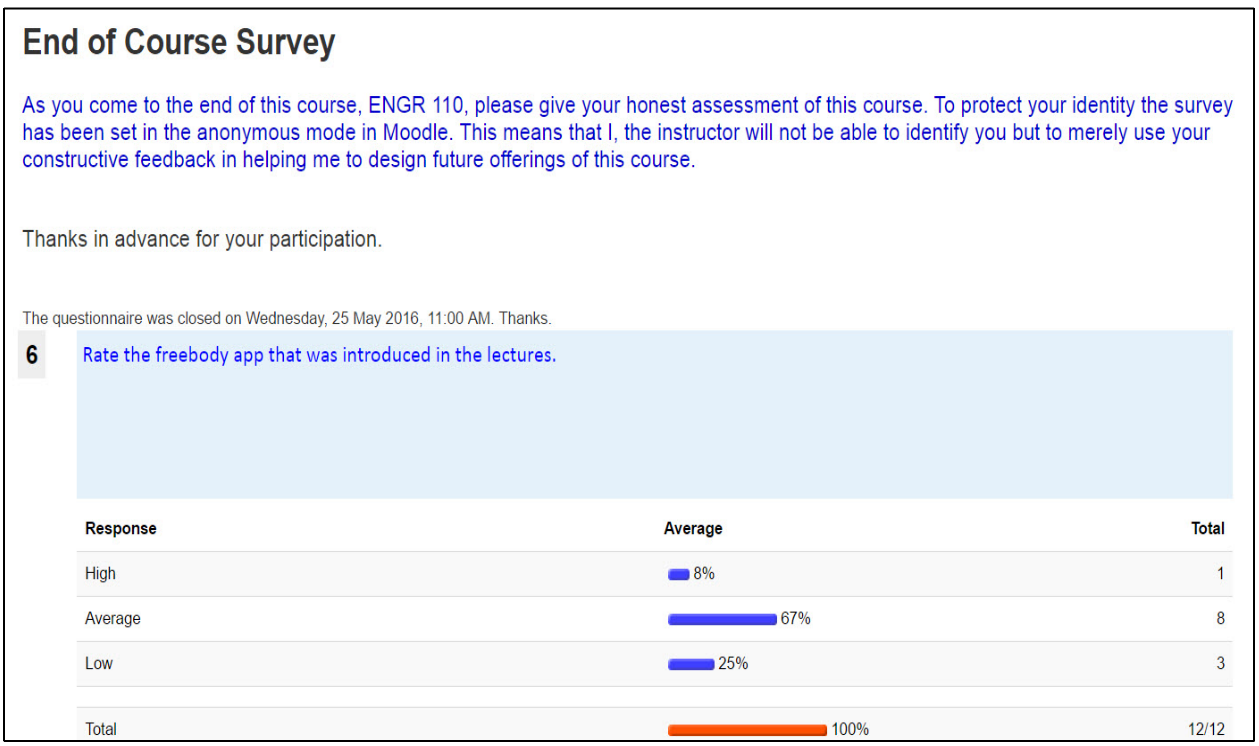


Figure 11. Feedback provided by the app in the case of an error

Figure 11 shows a situation in which an error has been made in the kinetic diagram. In this case the point of application of a force is incorrect. The feedback given to the student is shown in the highlighted area and a one-point score deduction is recorded in the bottom left portion of the screen. Note that a hint is provided and not the answer; this is to encourage the student to carefully examine the diagram and hopefully make the correction at the next attempt. The instructor or the student's peers can also provide help. Grades for the first attempt made by all students are recorded in a spreadsheet that is sent to the instructor. The first attempt is a good indicator of the student's ability to correctly draw the diagrams. The instructor is able to provide assistance to individuals during the class session as needed.

Assessment

The app was first introduced in the Fall 2015 semester and was also used in Spring 2016. In both semesters there was 10% average increase in the class GPA compared to the Fall 2016 when the app was not used. It must be noted that since the app was used only by one instructor, data for other faculty is not available. Responses related to the use of the app were obtained from the end of semester survey conducted in Spring 2016. The small sample size is due to the students' reluctance to complete surveys at the end of the semester; nonetheless the results gave an indication of how well the app was received. The App was evaluated primarily for (i) ease of use, (ii) comments or feedback provided when a student made a mistake, (iii) areas that needed improvement, and (iv) number of problems presented. This first edition had eleven examples. Figure 12 shows the rating given by the students. Figure 13 shows comments that elaborated on ratings provided in Figure 12. Students were encouraged to provide their opinion regarding what was good or bad and give suggestions for improvement of the app. It was necessary to get their perspective, as this would be instrumental in future revisions.



End of Course Survey

As you come to the end of this course, ENGR 110, please give your honest assessment of this course. To protect your identity the survey has been set in the anonymous mode in Moodle. This means that I, the instructor will not be able to identify you but to merely use your constructive feedback in helping me to design future offerings of this course.

Thanks in advance for your participation.

The questionnaire was closed on Wednesday, 25 May 2016, 11:00 AM. Thanks.

6 Rate the freebody app that was introduced in the lectures.

Response	Average	Total
High	8%	1
Average	67%	8
Low	25%	3
Total	100%	12/12

Figure 12. Student Rating of app

7

Briefly comment on what you liked or did not like about the app.

You may comment on

1. the ease of use
2. user-friendliness or feedback
3. areas that need improvement
4. number of examples, etc.

Response

The app was a bit picky, I would have liked to have more feedback.

1. Easy to use
2. I like the instant feedback

3. forces should be able to be placed anywhere along the line of action, and the labels in the drop down menu could be more clear

4. more examples could be helpful

I did not like how it was picky about where the weight forces were placed.

However, I did feel as if it was a good visual because there was also an animation.

Easy to use, but had problems with where the arrows should be applied. Some answers would allow the arrow to be pointing to the point of application and other required the arrow pointing away from the point of application. It did not specify which way it wanted arrows oriented and it would become frustrating to figure out.

It was good app, however they wanted the location of the forces at a certain place even if it was going in the right direction

Figure 13. Student Comments on Use of App

For the first attempt at creating the app, a rating of 75% is considered good. Students made the following suggestions: i) increased flexibility in the placement of forces is needed, and ii) more problems should be added. They commented that the animations were helpful. It must be noted that the app was only one instrument used in the entire course redesign. However the impact of this instrument was considered significant as it affected the student's performance in most areas including homework, tests and final exam.

The student learning outcomes for this dynamics course are: (i) *ability to apply knowledge of mathematics, science and engineering principles to analyze engineering problems Interpret mathematical or scientific work;*(ii) *ability to function on multidisciplinary teams;* (iii) *ability to identify, formulate, and solve engineering problems;* (iv) *recognition of the need for, and an ability to engage in life-long learning.*

The Working Model 2D project encouraged the students to apply independent research. Two websites were provided by the instructor; Interactive Physics Simple Machines – Lever[4] and

Working Model 2D Examples[5]. This dynamics course is required for all civil engineering and mechanical engineering majors, and most teams included members from each discipline.

The partial grade sheet revealed some interesting information about a student's overall performance in the course. In 2 lectures during each semester students were required to use the app to create free-body and kinetic diagrams in class. Figure 6 shows the grades recorded as students used the app.

The student's performance in solving a rigid body kinetics problem that required the creation of free-body and kinetic diagrams is shown in Figure [14]. The figure shows a comparison between student performances in the spring 2016 semester when the app was used and the fall 2016 semester when the app was not used. The sample sizes of 17 and 31 are the number of students who took the tests in the respective semesters. The questions asked in each test were not exactly the same but they dealt with the same topic, thus the percentages earned in the tests were used for comparison. Fifty-three percent of students earned a grade of 65% or higher in spring 2016 compared to thirteen percent in fall 2016.

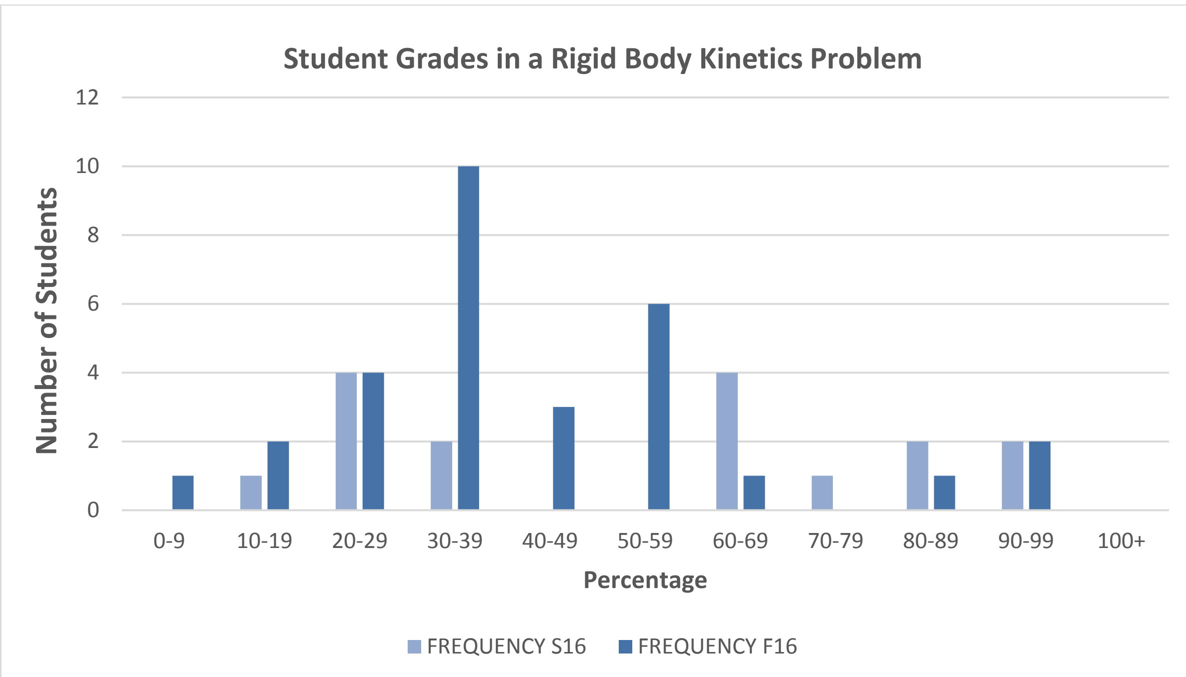


Figure 14. Comparison of Student Grades in a Rigid Body Kinetics Problem

It was observed that the final grades earned by students may be related to the number of problems attempted in the app as shown in Figure 15. The conclusion was that students that did not attempt the problems had very little chance of passing the course.

Records show that students who earned A or B grades attempted at least 85% of the problems. Even though it can be debated that other instruments used in the course redesign may have influenced a student's final grade, the correlation depicted in Figure 15 may not be merely coincidental. The impact of the app will be more obvious as the app is made available to and used by other faculty and students. Visualizing the motion of objects and correctly drawing the diagrams is necessary to successfully solve the problems in various areas of dynamics. The app

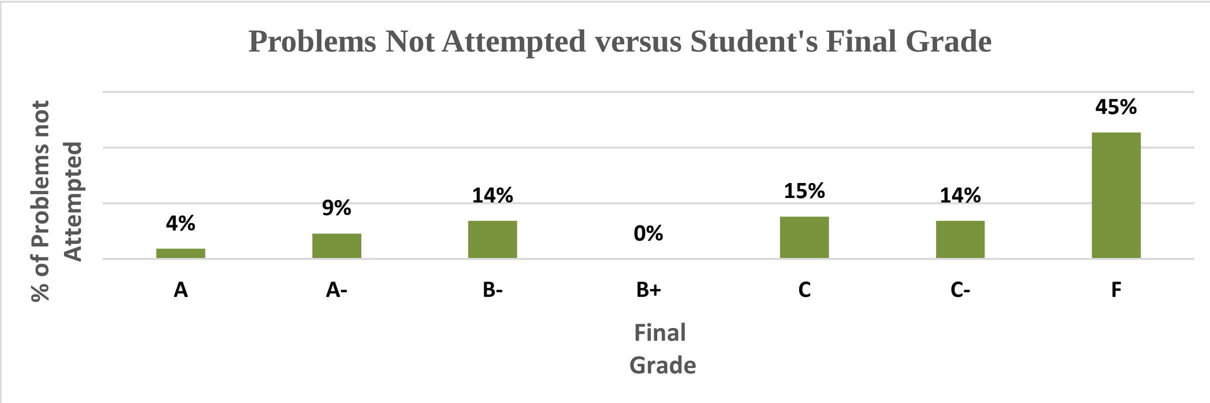


Figure 15. Correlation between Problems attempted in the app and final grade

provides a medium for practice that help reinforce these concepts so that the students can perform better in homework assignments, tests, and exams.

In the fall 2016 semester a deliberate decision was made not to use the app so that the effectiveness of the app could be measured. It can be concluded that the app had a positive impact on student learning and improved the student's ability to draw the diagrams. The limitation of the app is the number of problems available. The goal is to have at least 50 problems. There is a team of computer science students working to increase security in the grading database of the app and to allow for multiple access to other faculty who have expressed interest in using the app as a tutorial for students. It is anticipated that the goal of creating at least 50 problems will be reached and that the app will be available to students in other disciplines.

Acknowledgments

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Bibliography

1. Design Simulation Technologies. “Working Model 2D.” Web. 10 Jan 2015, http://www.design-simulation.com/WM2D/
2. Poku, Mike. Graduate Student, Department of Computer Science, California State University, Sacramento.
3. Hibbeler, R.C. “Engineering Mechanics DYNAMICS.” New Jersey: Pearson Education, Inc., 2015. Print.
4. n.p “Interactive Physics Simple Machines – Lever.” *YouTube*, Web. 18 Jan 2016, https://www.youtube.com/watch?v=9Zaws8oAn74.
5. n.p. “Working Model 2D Examples.” http://www.me.unlv.edu/~mbt/320/Working_Model.html, Web. 21 Jan 2016,
6. California State University Proven Course Redesign with Technology Grant, 2015-16.
7. Mose, J. Undergraduate Student, Department of Civil Engineering. California State University, Sacramento. December 2014.
8. Carthew, L. Undergraduate Student, Department of Mechanical Engineering. California State University, Sacramento. December 2015.