Enhancing student learning experience with a simulation tool in engineering dynamics

Ramadas Narayanan, Prasad Gudimetla, Sherre Roy and Aruna Jayasuriya.
Central Queensland University, Bundaberg, Qld 4670.
Corresponding Author Email: r.narayanan@cqu.edu.au

Introduction

Engineering Dynamics(ED) is a second year course in Mechanical Engineering program at CQUniversity which focuses on the development of the fundamental knowledge and concepts that help students understand, describe and predict the behaviour of dynamic systems. This knowledge is very important in the later stages of their engineering to pursue Advanced Dynamics, modelling, simulation and control of dynamic systems. Engineering Dynamics is that domain of Physics that seeks to explain the relationship between forces, the bodies on which they act, and the reactions that bodies exert due to such applied forces. This is a very complex task and historically, students have fared rather poorly at this course (Papadopoulos, Bostwick, & Dressel, 2007). The need to augment traditional teaching methods to enhance learning of this course is now very well recognised.

Engineering education has progressively embraced different forms of interactive learning and teaching protocols to augment traditional teaching methods. Central to these objectives has been the embedding of different modelling and simulation approaches to promote student-centred and self-paced learning environments; that help them understand complex topics.

Up until the early 2000s, such modelling and simulation software were the domain of upper level engineering students (MATLAB, MATHCAD, Finite Element Analysis (FEA) etc.). These are heavily reliant on user knowledge and discretion, with emphasis on advanced engineering applications. There are few opportunities for students to use simulation tools in units such as ED at the lower level which has created a user-knowledge gap and students are forced to a quantum leap in the use of such advanced modelling and simulation packages in the upper levels of their UG engineering degree. Unlike in units such as Mechanics of Solids, Strength of Materials and Design Engineering, which has seen the implementation of several interactive learning tools (Philpot and Hall, 2006; Prusty et al, 2001), there are very few interactive tools for ED, barring some applets (see EN4: Dynamics and Vibrations, Brown University) which are geared more towards visualisation.

An additional challenge for educators is to instil self-learning and discovery attitudes in students in the lower levels of undergraduate engineering programs, particularly as they move from the generic engineering subjects to core areas as the learning concepts become more technical. There is ample evidence (Baillie and Fitzgerald, 2000; French et al, 2005, Haag S., et al, 2007) to support the higher levels of attrition in engineering as compared to other disciplines. One of the main reasons is students' loss of confidence and persistence the moment they encounter complex technical concepts that lack proper support structures to help them unpack the complexities.

There is thus, an imperative need to redesign learning pedagogy in subjects such as ED by adopting interactive learning tools that (i) help students to understand simple and complex concepts with equal ease; (ii) motivate them to undertake further exploration within the topical areas and (iii) prepare them to embrace more sophisticated simulation tools in the upper levels of engineering. IP is a very proactive software that allows students to model any engineering problem very easily and study its behaviour under different boundary conditions, and within defined physical and mathematical frameworks. They are able to generate different types of numerical, analytical and graphical outputs and relate a system's behaviour as governed/predicted by physical laws. IP is a discovery-oriented self-learning system that

helps students learn and understand many complex abstract engineering concepts that are critical to their further success at the upper levels of the engineering program.

Several studies on using simulation packages to augment learning the difficult concepts in other disciplines like population genetics (Leach & Pietsch, 2000), in health (Rudd, 2013), Banking (Fenech, 2015) and Nursing (Levett-Jones, 2011) using different software applications shows that it is effective at different student levels, but there is no such study in Engineering Dynamics. So this project aims to evaluate student experiences of using interactive simulation to learn engineering concepts by introducing IP in an Engineering Dynamics course.

Research Design

A combination of quantitative and qualitative methods were used for data collection in this project. The quantitative aspect is to identify changes in students' perceptions of their learning and preparedness, while the qualitative aspect is to gain a deeper understanding of how the students used the simulation software and its impact on their learning experiences. The target concepts for this study are rectilinear kinematics, projectile motion, curvilinear kinematics, dependent motion, particle kinetics, impact, impulse, translation, fixed axis rotation, rigid body kinetics and free, forced and damped vibrations.

The participants are students enrolled in the ENEM12010 Engineering Dynamic Course in Term 1, 2019. All students are asked to complete Kinematics, Kinetics and post-simulation surveys. The surveys will be scheduled at end of kinematics topics, kinetics topics and at the end of the unit as target concepts are taught progressively during the duration of the course. For the survey, student's anonymity are maintained and participation in the interviews will not impact student marks and/or grades.

Questionnaire Surveys

The different topics are delivered initially through lectures and tutorials and then simulation exercises are given to the students. Surveys are conducted with students after introduction of simulation software application to ascertain their learning experience. The Likert Scale is used to scale the responses of the surveys and are analysed to estimate any statistically significant attributes from the use of the simulation package.

The simulation software is introduced in Week 3 and some of the concepts discussed in the first 2 weeks are simulated and revisited to expose the efficacy of the software in grasping some of the complex concepts. The surveys are administered in Weeks 4, 10 and 12. Students are asked appropriate questions quantitative survey questionnaire to compare their experiences on conceptual understanding with and without using the simulation software.

Simulation Exercises

Interactive Physics Exercises

Exercise 1- Kinematics
1. Start the software IP (Interactive Physics)

2. Open the demonstration file and run the following simulation from C:\Program Files (x86)\Interactive Physics\PhysicsExperiments\MotionInOneDimension
   a) Click 'ConstantAccleration'. Click the 'Run' button in green and observe the results.
   b) Change the acceleration values and see the changes in x-t, v-t and a-t graphs.

3. Watch the following video and carry out the exercise in the IP.
   ScienceMan Digital Lesson - Physics - Interactive Physics Review
   https://www.youtube.com/watch?time_continue=10&v=nCCC07bCAaE

4. Open the demonstration files and run the following simulation from C:\Program Files (x86)\Interactive Physics\PhysicsExperiments\MotionInOneDimension
   a) Click 'Linear motion of Jet'. Click the 'Run' button in green and observe the results.
   b) Change the Mass and Thrust values and see the changes in x-t, v-t and a-t graphs.

5. A particle in rectilinear motion with $x = 2t^3 - 15t^2 + 24t + 4$.
   a) Draw s-t, v-t and a-t graphs of this motion in a graph paper.
   b) Calculate x, v and a when t= 2s using the expressions of displacement, velocity and acceleration.
   c) Run the simulation on 'Rectilinear motion' given in the folder C:\Program Files (x86)\Interactive Physics\PhysicsExperiments\MotionInOneDimension.
   d) Check the answers of steps a & b.

Exercise 2 – Kinetics

1. Watch the following video and do it in the IP.
   Interactive Physics Simple Machines – Lever
   https://www.youtube.com/watch?v=9Zaws8oAn74

2. Start the software IP (Interactive Physics)
   a) Open the demonstration file and run the following simulation from C:\Program Files (x86)\Interactive Physics\IPCurriculum\StraightLineFMA.
   b) Click 'StraightLineFMA 1'. Click the 'Run' button in green and observe the results.
   c) Change the acceleration of rocket and observe the changes.
   d) Verify these with actual calculations.

3. Repeat the steps of a,b,c and d of the above with the other demonstration files.

4. Use Interactive Physics to simulate Problem 3-17 from the textbook (Engineering Mechanics- DYNAMICS by R.C. Hibbeler, 14 Edition). Compare the textbook solution and Interactive Physics solution.

   Determine the acceleration of the blocks when the system is released. The coefficient of kinetic friction µ and mass of each block is m. Neglect the mass of the pulleys.
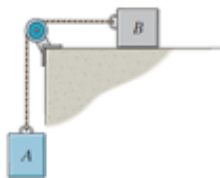

Figure 1 : Problem 1 Kinetics

5. Use Interactive Physics to simulate the following problem. Compare the calculated solution and Interactive Physics solution.
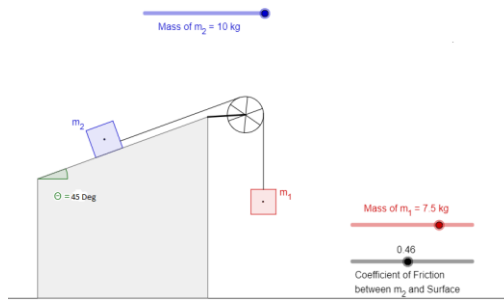
Figure 2 : Problem 2 Kinetics

Survey Questionnaire

The following Questionnaires are used to for the Week 4 Kinematics and Week 10 Kinetic survey.

Q1.   The simulations help me to understand the concepts of [topic]

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q2.   The simulations help me understand the mathematics behind concept of [topic]

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q3.   The simulations greatly simplify the problem statement

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q4.   The simulations help me understand the connections between the physics of and the mathematics behind various [topic] problems

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q5.   The simulations helped me to learn about [topic]?

 Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

The following questionnaire is used for post-simulation Survey administered Week 12.

Q1.   The simulations help me to understand the concepts and physics of dynamics problems

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q2.   The simulations help me understand the mathematics behind dynamics problems

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q3.   The simulations greatly simplify the problem statement

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q4.   The simulations help me understand the connections between the physics of and the mathematics behind various dynamics problems

Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Q5.   The simulations helped me to learn about dynamics

 Strongly agree / agree / neither agree nor disagree/ disagree / strongly disagree

Results

Table 1: Week 4 Kinematics Survey

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
Q1	53%	36%	12%	0%	0%
Q2	35%	36%	28%	0%	0%
Q3	53%	29%	18%	0%	0%
Q4	64%	18%	18%	0%	0%
Q5	70%	30%	0%	0%	0%

Table 2 : Week 10 Kinetic Survey

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
Q1	53%	36%	12%	0%	0%
Q2	30%	40%	30%	0%	0%
Q3	50%	50%	0%	0%	0%
Q4	70%	30%	0%	0%	0%
Q5	70%	30%	0%	0%	0%

Table 3: Post simulation Survey

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
Q1	57%	28%	0%	0%	15%
Q2	57%	28%	0%	0%	15%
Q3	67%	33%	0%	0%	0%
Q4	57%	28%	0%	0%	15%
Q5	86%	0%	0%	0%	14%

Conclusions

The pedagogical strengths of incorporating IP into teaching Engineering Dynamics can be summed as:

- IP helps students to readily visualise the behaviour of bodies and mechanisms as they would happen in real time and space.

- IP provides engaging simulations by helping students manipulate the input parameters to explore their effects which in turn promotes deeper learning.

- The outputs of simulations allow students to make easy connections with real-life experiences.

The results show that the use of Interactive Physics has enhanced the learning experience considerably and helped not only to understand the concepts in kinematics and kinetics, but also to know the mathematics behind it. It also helped make connections between physics and mathematics behind the various dynamics problems and effective and simplified the problem statement.

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