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Addressing learning difficulties in Newton’s 1st and 3rd Laws through problem based inquiry using Easy Java Simulation

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We develop an Easy Java Simulation (EJS) model for students to visualize Newton’s 1st and 3rd laws, using frictionless constant motion equation and a spring collision equation during impact. Using Physics by Inquiry instructional (PbI) strategy, the simulation and its problem based inquiry worksheet aim to enhance learning of these two Newtonian concepts. We report results from Experimental (N=62 students) and Control (N=67) Groups in 11 multiple-choice questions pre- and post-tests, conducted by three teachers in the school. Results suggest, at 95% confidence level, significant improvement for concept of Newton’s 1st Law while not so for Newton’s 3rd Law. A Focus Group Discussion revealed students confirming the usefulness of the EJS model in visualizing the 1st Law while not so much for the 3rd Law. We speculate the design ideas for constant velocity motion in the computer model coupled with the PbI worksheet did allow for ‘making sense’ and experiencing of the 1st Law, where traditional pen-paper representations could not. We have improved the features for the action-reaction contact forces visualization associated with the 3rd Law and we hope other teachers will find the simulation useful for their classes and further customize them to benefit all mankind, becoming citizens for the world.

Keyword: easy java simulation, active learning, education, teacher professional development, e-learning, applet, design, open source, GCE Advance Level physics

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I. INTRODUCTION

Physics by Inquiry (PbI) as an instructional strategy in a local school has gained popularity, but results from the localized version of the Force Concept Inventory (FCI) suggests students still harbor commonsense beliefs about motion with forces (Halloun & Hestenes, 1985), inconsistent with Newton’s 1st and 3rd laws. This is probably due to a combination of many factors, one of the main causes is the difficulty to “make sense” (Wee, 2012a) of the phenomena, without learning by first person experiencing (Oblinger, 2004; Wee, 2012b) and contextualizing in “real-life referents” (Dede, Salzman, Loftin, & Sprague, 1999), hence leading to what is commonly referred to as the abstract nature (Chabay & Sherwood, 2006) of learning physics.

We argue that computer simulation could be an appropriate substitute for active learning referents, provided simulations are carefully developed (Weiman & Perkins, 2005), used in appropriate context (Finkelstein et al., 2005), aided with challenging inquiry activities (Adams, Paulson, & Wieman, 2008) and facilitated by teachers who believe (Hsu, Wu, & Hwang, 2007) in the effectiveness of the tool.

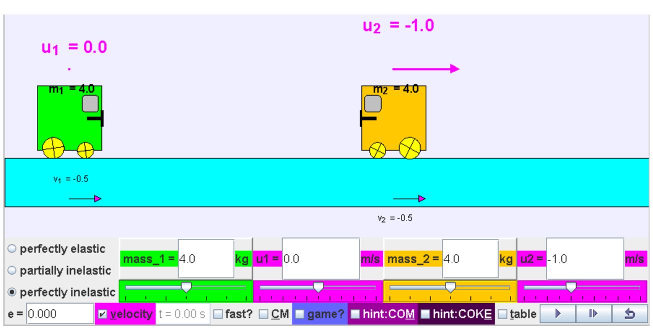

Figure 1. EJS applet view of the virtual laboratory simulation learning environment showing a world view, and a bottom control panel for student-directed inquiry activities where students are able to make sense of Newton’s 1st and 3rd Laws.

Building on open source codes shared by the Open Source Physics (OSP) community like, Francisco’s example of “Collision in one dimension” (Esquembre, 2009), Andrew’s (Duffy, 2010) One Dimensional Collision Model for game design, and Fu-Kwun’s many other examples on NTNUJAVA Virtual Physics Laboratory, we further customize an Easy Java Simulation (EJS) (Wee & Esquembre, 2008) computer model into a virtual laboratory as shown in Figure 1 (Wee, Esquembre, & Lye, 2012), that we hope many teachers will find useful and can act more intelligibly (Juuti & Lavonen, 2006) in their own classes.

II. PHYSICS MODEL

In this simulation, the two-body collision carts model is simulated by constant velocities motion as equations (1) and (2), assuming that the x position of the centre of carts 1 and 2 are x_1 and x_2 respectively and their instantaneous velocities v_1 and v_2 respectively (see Figure 2).

$$\frac{dx_1}{dt} = v_1 \tag{1}$$

$$\frac{dx_2}{dt} = v_2 \tag{2}$$

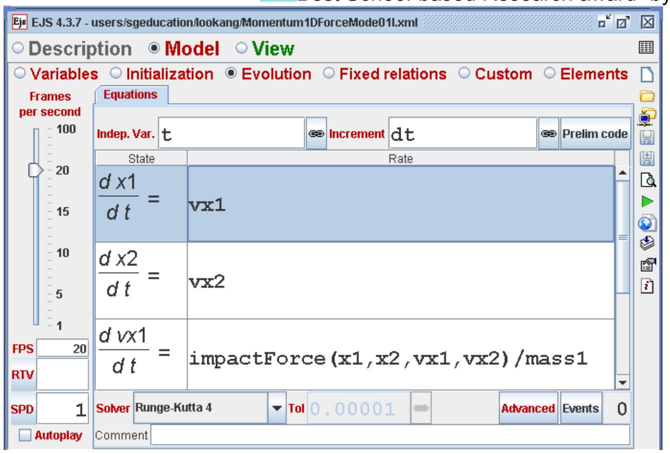

Figure 2. EJS authoring tool view at the 'Evolution Page' showing equations (1) and (2) as ordinary differential equations (ODE) with time *t* as the independent variable and *dt* as the increment.

Notice how easily these equations simulate carts that continue in uniform *x* direction motion without any loss of energy as described by Newton's 1st Law.

The contact impact force is modeled by equation (3) as adapted from Brach (2003, p. 3) where *k* is a linear spring constant, *es* is the coefficient of restitution, m_1 and m_2 are masses of carts 1 and 2 respectively.

$$F_{impact} = -2\sqrt{\frac{\log(es)^2}{\pi^2 + \log(es)^2}}\sqrt{k(\frac{m_1 m_2}{m_1 + m_2})}(v_1 - v_2) + k(x_1 - x_2) \quad (3)$$

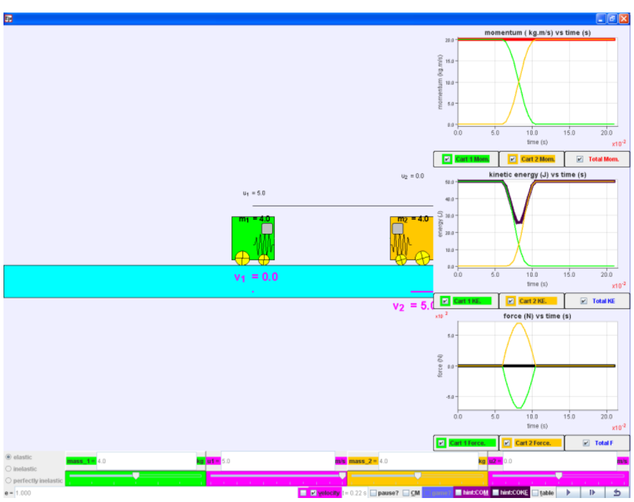

Figure 3. Collision carts (realistic) model (Wee, Esquembre, et al., 2012) derived from Francisco's original work (Esquembre, 2009) with three scientific graphs showing realistic spring modelled during collisions.

This Physics model (see Figure 3), when implemented in a simulation, allows experiencing and 'messing about' productively (Finkelstein, et al., 2005, pp. 010103-010107); and serving as a powerful referent tool (Dede, et al., 1999) for learning.

III. Method

This study investigates whether students from the experimental group who have undergone the PbI problem based inquiry lesson using a finer customized EJS computer model will have a better learning experience than their peers in the control traditional-teaching group. Our team of three teachers each selects two of their classes to participate in this research study. The classes are assigned with the intention of creating equivalent groups of similar class size and similar mean subject grade of 2.00 equivalent of 'B' grade (Table I) in their Ordinary Level Physics. The same teacher participating in both groups serves to reduce the instructor effect.

Table I. Class sizes of Experimental and Control Groups of the instructors. Mean Subject Grades of Experimental and Control Groups are similar.

Instructor	Experimental Group (EG)	Control Group (CG)
YKW	23	24
AG	22	21
JT	17	22
Total	62	67
Mean Subject Grade (MSG)	2.00 ='B'	2.00 ='B'

Prior to attending lessons on the topic of "Dynamics", the entire cohort of about 400 Physics students in this school took a pre-test based on a selection of 15 questions from the Force Concept Inventory (FCI), which focuses particularly on Newton's three Laws. Out of the 15 questions, our test data was collected from seven multiple-choice questions (MCQ) on Newton's First Law (N1stL) and four MCQ on Newton's Third Law (N3rdL). After the topic was completed after 2 to 3 weeks, the students took a post test, identical to the pre-test. Furthermore, two questions about N1stL and N3rdL were specially crafted for their Mid-Year Common Test to assess the longer term transfer of their conceptual change.

Focus Group Discussion (FGD) with 9 students, three students from each experimental class was conducted where they were to reflect on their learning experience so that the lesson package of worksheet and computer model can be further improved.

IV. Results and Discussions

Using Z-test as in equation (4), for Newton's 1st Law, the Z-value is 2.23 where |Z| > 1.96 (see Table II). There is sufficient evidence at 5% significance level to reject the null hypothesis that the Experimental Group did not do better than the Control Group for Newton's 1st Law.

$$Z = \frac{(\overline{X_1} - \overline{X_2}) - (\mu_1 - \mu_2)}{\sqrt{\frac{\sigma_1^{\ 2}}{N_1} + \frac{\sigma_2^{\ 2}}{N_2}}} \quad (4)$$

Table II. Pre-and post-tests scores categorized according to question type; Newton's 1st Law (7 marks) and 3rd Law (4 marks) for the Experimental (N_1=62) and Control (N_2=67) Groups.

Question Type	Group	Pre-test score µ	Post-test score X	Difference (X-µ) σ	Probability value

$N1^{st}L$ (7 marks max)	N_1= 62	3.968 1.736	4.774 1.562	0.806 2.055	P(|Z| < 2.23) =0.974
	N_2= 67	4.612 1.477	4.716 1.485	0.104 1.447	
$N3^{rd}L$ (4 marks max)	N_1= 62	2.065 1.143	2.823 1.138	0.758 1.224	P(|Z| < 0.76) =0.552
	N_2= 67	2.060 1.071	2.970 0.953	0.910 1.041	

However, for Newton's 3rd Law, the Z-value is -0.76 where $|Z| < 1.96$. There is insufficient evidence at 5% significance level to reject the null hypothesis that Experimental Group did not do better than the Control Group for Newton's 3rd Law.

In addition, Experimental Group continued to perform better in Newton's 1st Law in the Mid-year common test. However, the Experimental Group did not perform better in Newton's 3rd Law (Table III).

Table III. Mid-year common test scores categorized according to question type; Newton's 1st Law (2 marks) and 3rd Law (2 marks) for the Experimental (N_1=62) and Control (N_2=67) Groups.

Question Type	Group	Mid-year test score *Y*
N1stL (2 marks max)	N_1=62	1.032 0.829
	N_2=67	0.836 0.853
N3rdL (2 marks max)	N_1=62	0.032 0.254
	N_2=67	0.164 0.559

This gap in the learning of the 3rd Law has allowed for the implementation of new design idea-features such as clearer and slow motion visualization of contact forces during collision and larger mass having proportional larger area representation, which we will test out in future research lessons (see Figure 4).

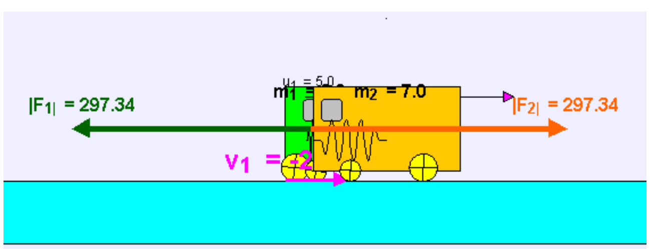

Figure 4. Collision carts (realistic) model (Wee, Esquembre, et al., 2012) with design feature-ideas to bring out the concepts of Newton's 3rd Law where the contact forces are clearly represented as equal, opposite and acting on different bodies even for masses that are different.

We include excerpts of the Focus Group Discussion and informal interviews with the students to give some themes and insights into the conditions and processes during the problem based inquiry lessons. Words in brackets [] are added to improve the readability of the qualitative interviews.

1) Computer model allows visualization

"This is more for visual learners. They can see how they actually collide, in which direction and what will be the results."

"The computer model will help you to see the [representation of] forces acting at any one instant, unlike the real collision carts demonstration set [which are invisible]."

2) Need for balance between student direct inquiry and teacher direct instruction

"Overall I feel that this project is useful because it enforces self-exploration of the interactions between colliding objects and this is especially useful for those with inquisitive minds as they are able to configure the velocity as well as the type of collision."

"With teacher demonstrating the use of computer models, logistically more efficient, but learning wise may not be better [because student need to direct the inquiry to deepen their understanding]"

3) Need for real equipment to relate to the real world

"Actually the programme [computer model] does help in some ways, but ……. we [still] can't really relate this to real life situations."

"I think it's quite closely related to our syllabus and can use this live experiment to foster a deeper understanding of how the force works (in collision carts)."

Readers could explore use of Tracker (Brown, 2012; Wee, Chew, Goh, Tan, & Lee, 2012; Wee & Lee, 2011) to allow students to inquire into videos of real collisions for a stronger connection of scientific concepts to real life applications.

V. Conclusion

The theoretical physics model of a two-body realistic collision system in one dimension is discussed and implemented in EJS and the equations (1) to (3) should be applicable to any modeling tool such as VPython (Scherer, Dubois, & Sherwood, 2000) or Modellus (Teodoro, 2004).

Our research data using Z-test suggests that at a 95% confidence level, students who underwent treatment of PbI worksheet with our customized EJS computer model (N=62) performed better in Newton's 1st Law than their peers who otherwise underwent the traditional instructions (N=67). Focus Group Discussion with students and discussions with teachers suggest the computer model design and its pedagogical use as a tool did allow students to 'make sense' and experience the 1st Law.

We hope this paper adds to the body of knowledge when computer models are used for interactive engagement (Hake, 1998) by the students. We also hope that computer models can provide experiential learning (Wee, 2012b) and sensing; making visualization better which is not possible through traditional paper media.

We have since improved on the computer model for better visualization of the 3rd Law with design ideas as shown (see Figure 4).

We hope teachers will find the worksheet and computer model (https://www.dropbox.com/s/gf1vc7qqy7l47y8/CollsionCartsAJCworksheets.zip and https://www.dropbox.com/s/8sgjazk5dohj5sk/ejs_Momentum1DForceModel01.jar) useful and can act more intelligibly (Juuti & Lavonen, 2006) in their own classes.

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