

Comparing Three Methods for Teaching Newton's Second Law

Michael C. Wittmann and Mindi Kvaal Anderson

Department of Physics and Astronomy; College of Education and Human Development; Center for Science and Mathematics Education Research; University of Maine, Orono, Maine 04469, USA

Abstract. As a follow-up to a study comparing learning of Newton's Third Law when using three different forms of tutorial instruction, we have compared student learning of Newton's Second Law (NSL) when students use the Tutorials in Introductory Physics, Activity-Based Tutorials, or Open Source Tutorials. We split an algebra-based, life sciences physics course in 3 groups and measured students' pre- and post-instruction scores on the Force and Motion Conceptual Evaluation (FMCE). We look at only the NSL-related clusters of questions on the FMCE to compare students' performance and normalized gains. Students entering the course are not significantly different, and students using the Tutorials in Introductory Physics show the largest normalized gains in answering question on the FMCE correctly. These gains are significant in only one cluster of questions, the Force Sled cluster.

Keywords: Newton's Laws, Force and Motion Conceptual Evaluation (FMCE), tutorials.

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INTRODUCTION

It is well known that guided-inquiry University of Washington-style tutorials can be effective supplements to traditional methods of teaching. Previously, we compared three common published tutorials on the topic of Newton's Third Law [1]. To extend the previous study, we examined the learning outcomes of three different tutorials about Newton's Second Law (NSL): the University of Washington's *Tutorial in Introductory Physics* [2], the University of Maryland's *Activity Based Tutorials* [3], and the University of Maryland's *Open Source Tutorials* [4]. Each introduces NSL in a different way. NSL requires two major ideas: the superposition of forces and an understanding of acceleration as a change in motion caused by the net force on an object. One can argue that introducing one idea before the other has greater value; for example, having a single force and helping students understand its effect as causing an acceleration might be easier than dealing with many forces that somehow lead to no acceleration. We used the Force and Motion Conceptual Evaluation [5] to compare the effectiveness of the three tutorials.

RESEARCH-BASED TUTORIALS

All three tutorials in this study use guided inquiry

methods as a basis for teaching NSL. Students work in groups of three or four on worksheets that ask them to qualitatively answer questions with less emphasis on number crunching than what is found in standard physics textbook activities. All tutorials assume some knowledge of NSL and kinematics but do not require the use of calculus or other advanced mathematics.

Tutorial in Introductory Physics

The Tutorial in Introductory Physics (TIP) tutorials are designed to elicit student reasoning, confront them with contradictions based on incorrect answers, and resolve any problems they have with the physics. The first part of a typical TIP tutorial is designed to elicit specific student difficulties by presenting a surprising or counter-intuitive situation. Students are presented with questions written to create cognitive conflict. Often, the resolution of the physics ideas, as well as the extensions of the newly learned ideas, is in the homework that accompanies the tutorial.

The TIP tutorial introduces NSL by investigating the "at rest" condition using a paper and pencil tutorial. Multiple forces act on a single stationary object. Only in the homework (which was not assigned in this study, as explained below) are situations with constant speed and accelerated motion considered.

Activity –Based Tutorials

The Activity Based Tutorials (ABT) use hands-on laboratory-like experiences and computer-based data collection to explore physics. The ABT are designed to be like TIP materials, with a mindset of elicit-confront-resolve, though the method is implemented differently. In the ABT, the resolution of one's difficulty with the physics is typically not in the homework, but placed within the tutorial.

The ABT tutorial introduces NSL by investigating motion with acceleration by using “frictionless” carts and computer graph outputs. Students use motion detectors to take data about fan carts experiencing accelerated motion due to a fan providing a constant force on the cart. Only toward the end of the tutorial are multiple forces considered. Thus, the emphasis is on the relationship between force and acceleration, and not on static situations due to the superposition of forces.

Open Source Tutorial

The Open Source Tutorials (OST) use a “refining intuitions” approach where student's intuitions and beliefs about the world around them are taken into account to build new ideas. Rather than finding student difficulties and helping students resolve their difficulties, the OST help students understand when their intuitive ideas are applicable and when not. They share with the ABT and TIP the steps of eliciting and confronting incorrect ideas, but the process of resolution is explicitly one of refining existing (and misapplied) intuitions.

The OST tutorial introduces NSL by investigating vertical motion situations and comparing the constant speed situation with speeding up and slowing down situations. There is a superposition of forces as well as an explicit comparison of the magnitudes of these forces. Thus, the OST differs from both the ABT (no superposition, accelerated horizontal motion) and TIP (superposition, no motion).

RESEARCH DESIGN

Research for this study was conducted during the fall of 2008 in the first half of a two-semester sequence in algebra-based introductory physics at the University of Maine. The course covers linear and rotational kinematics and dynamics, work and energy, simple harmonic motion, and wave propagation. The students are primarily life science, earth science, and forestry majors.

The course consists of two fifty-minute lecture sections, two fifty-minute small-group discussion

sections, and one two-hour laboratory period per week. All students attend a common lecture section and choose their small-group discussion and laboratory sections. In the fall of 2008, there were five discussion sections dedicated to tutorials, each tutorial being given 2 hours over 2 days. Each section had at most 24 students and 1 teaching assistant (TA) as facilitator.

All students had used tutorials from each of the published and studied curricula (TIP, ABT, OST) in the first few weeks of instruction. We expected students to be familiar with pencil-and-paper tutorials, tutorials using MBL, and refining intuitions tutorials. For our study, the five discussion sections were split up randomly, with four sections getting one form of NSL tutorial. One section split in half – half the tables using one tutorial, half another. Students were not allowed (or able) to complete more than one type of tutorial.

Because of choices made by the course instructor, no tutorial homework was assigned to the students. Thus, they had no opportunity to practice their ideas outside of the tutorial setting. The course homework was solely from the textbook. Also, there were no specific tutorial-based examination questions in this course. Though students were required to attend tutorials, there were few built-in incentives for them to engage deeply with the material outside of class.

We gathered data using the Force and Motion Conceptual Evaluation (FMCE). The FMCE was administered at the beginning and end of the semester as part of the students' regular course work in discussion sections.

A scoring template for the FMCE created by Michael C. Wittmann and later refined by Trevor Smith was used to score the FMCE [6]. The seven clusters identified within the template are the Force Graph, Force Sled, Reversing Direction, Velocity Graphs, Acceleration Graphs and Energy clusters. In total 37 questions are quantified, with a perfect score of 33 (without including the energy cluster) or 37 (when including the energy cluster). Scoring with the template provides the instructor with a total overall score and a look into student performance in each of the seven content areas. Four clusters with 27 questions explicitly address NSL (see Table 1).

DATA AND ANALYSIS

The three tutorials introduce NSL in different ways and using different physics principles: the TIP uses the at rest condition and the superposition of forces, the ABT uses accelerated motion with one dominating force, and the OST uses primarily constant speed motion and the superposition of forces. We evaluated whether the choice of a single tutorial within a larger

TABLE 1. NSL Clusters on the FMCE. Some questions are omitted by recommendation of the test authors.

Cluster	Questions
Force Sled	1-4, 7
Reversing Direction	8-13, 27-29
Force Graph	14, 16-21
Acceleration Graph	22-26

instructional sequence can have lasting effects on student learning. Given that a semester includes six hours/week of instruction over 14 weeks, the change of one tutorial is unlikely to have a notable effect. We measured student learning by computing gains on the FMCE in the area of NSL and comparing these gains between similar populations split among the three different tutorials.

There were 116 students enrolled at the beginning of the semester. A total of 75 students completed both a pre- and post-test FMCE. Three of these students did not complete a tutorial. Thirteen students would have been included in the matched data set had they put their names on the FMCE post-test; most of these would have been part of the TIP group, but not all. Thus, they are left out of the data analysis. In total, there are 72 fully matched data points. Of the 72 matched data points, 34 were in the ABT group, 22 were in the OST group, and 16 were in the TIP group. We look at differences between these differently sized groups. We used R (<http://www.r-project.org/>) to carry out our statistical analysis.

Scores from both the pre- and post-test FMCE were analyzed for raw score and normalized gains in the overall score and in each NSL cluster. We first determined whether students could be considered equivalent before any instruction. Using the overall pretest FMCE score is a basic test that leaves out information about past experiences and abilities, but serves as a basic measure of student equivalence. The pre-test FMCE scores for the three groups was compared using ANOVA, with a p-value of 0.678. We concluded that the incoming FMCE scores for each tutorial group were not significantly different. For our purposes, we considered the three student populations to be equivalent.

Overall scores on the FMCE increased for the entire population but were very low both in the overall and the individual cluster scores. Still, with similar pre- and different post-instruction scores, there normalized gain for each tutorial group was different.

The overall gains for each tutorial group are shown in Table 2. The gains between tutorial groups were determined to be significantly different (throughout, we determine significance as having $p < 0.05$). A piecewise comparison was performed to determine which tutorial group's gains were significantly different from the other groups. It was found that that

the TIP tutorial group showed significant gains in overall scores on the FMCE over the ABT tutorial group.

Total (overall) FMCE gains and gains in the four areas of NSL are shown in Figure 1. The TIP group had the largest overall gains and also demonstrated the largest gains in each of the NSL clusters. It also appears that the three groups may have had significantly different learning gains on the Force Sled, Force Graph and Acceleration Graph clusters.

The inclusion of error bars with the FMCE gain graph suggests misleading differences between the three groups. The error bars are calculated by finding the average standard error. This takes into account overall group gains on the pre- and post-test FMCE and the sample size. It appears that there are significant differences in gains all clusters but the Reversing Direction cluster.

We found instead that the gains were only significant for the Total scores, as described above, and for the Force Sled cluster. Gains in both the Force Graph and Acceleration Graph clusters are not significantly different, though they appear to be in Figure 1. In both cases, changes in scores are primarily due to outliers – those few students who had large changes in their scores. For the Force Graph cluster, 50 of 72 students had gains of zero, while for the Accelerations Graph cluster, 37 of 72 students had gains of zero. The error bars representing average standard error do not take into account matched data points and individual gains but instead look at overall group gains. For this reason the error bars are not sufficient to determine significant differences when comparing gains between tutorial groups. Further

TABLE 2. FMCE Gains in by Tutorial Group

Tutorial Group	Overall Gains
TIP	0.21
ABT	0.10
OST	0.14

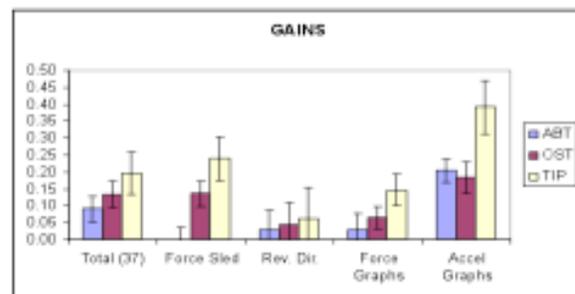


FIGURE 1. FMCE gains for each tutorial group. Gains for total (with energy cluster) and Newton's Second Law clusters. Error Bars represent average standard error for total gains of all group members.

analysis of the Force Sled cluster FMCE data found that the TIP group performed significantly better than the ABT group but not significantly better than the OST group.

DISCUSSION

We are curious to know how different forms of instruction affect student learning as a way of observing the sources of changes in student understanding. In an algebra-based introductory physics course at the University of Maine, with students having otherwise identical instruction, we split the student population as evenly as possible and gave each group of students a different form of tutorial instruction.

The TIP group demonstrated the largest gains, with gains on the overall test that were significantly different from those of the ABT group. In terms of the NSL clusters on the FMCE, it was shown that the TIP group showed the largest gains in all four areas, but only one was significant. The gains of the TIP group were shown to be significantly greater than the ABT group on the Force Sled cluster. Students whose tutorial focused on the at-rest condition in a pencil-and-paper situation using elicit-confront-resolve methods showed better learning gains on the FMCE than those using the MBL methods in an elicit-confront-resolve situation without an emphasis on the at-rest condition. Students whose tutorial used a refining intuitions approach were in between these two tutorials, on average.

We cannot determine what aspect of the different tutorials may or may not have had an effect on student learning. As pointed out previously [7], the at-rest condition is a necessary part of learning about NSL. Both the ABT and OST assume a knowledge that the TIP develops with students. Furthermore, the Force Sled question deals with “natural language” questions, while the other NSL questions deal with graphing or the much more difficult topic of reversing directions. We were surprised that the ABT materials, which emphasize graphing, were not more successful on the graphing questions. Furthermore, while the Newton’s Third Law tutorials (described in [1]) showed significantly higher gains for the OST materials than the ABT and TIP, it is possible that the NSL tutorial in the OST materials is less effective because there is less intuitive buy-in from students about the consequences of unbalanced forces on the acceleration of an object.

Finally, there were problems with the implementation of the tutorials. It is possible that the implementation of tutorials was flawed due to the lack of tutorial homework and targeted examination questions, and that this affected student motivation and

learning. We do not know if other measures (such as well designed pretest and examination questions) would have led to the same results. We did ask a targeted final examination question, but performance was so poor across the board that it did not give information about differences in student results. Also, tutorial facilitators may have been more familiar and comfortable with the TIP materials (which had been used in previous years) than with the ABT or OST materials (which were new to all facilitators). We plan to address some of these concerns in a follow-up study in 2009.

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