Using IOLab to Correct Student Misunderstandings of Newton's Third Law

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Introduction and Experimental Design

An analysis of the FCI diagnostic pre-tests taken by students in the calculus and algebra-based introductory physics courses at Millikin University showed that the questions most missed dealt with Newton's Third Law, even for students who scored highly overall. This analysis was confirmed throughout the fall semester, as students routinely struggled with conceptual questions dealing with applications of the Third Law.

Our hypothesis was that students had difficulty visualizing the forces present during interactions, and the IOLab device, developed at the University of Illinois, provided a hands-on means to give students a chance to "see" these forces and compare them. Students from introductory physics classes were given an opportunity to earn extra credit by performing in this study. All subjects had completed at least one semester of instruction in physics, including Newton's Laws. Subjects were asked to complete a pre-test and post-test with questions pertaining to Newton's Third Law, and in between, they worked through a guided lesson using the IOLab. The post-test questions were taken from the FCI, and the pre-test questions were designed to probe understanding of the basic third-law concepts..

The IOLab lesson guided students through four scenarios.. The first scenario had two devices placed on an incline equal distances apart, with equal masses (see Fig. 5). The devices were released at the same time so that they crashed into each other at the bottom of the inclines. The second scenario was exactly like the first except one of the devices had additional masses placed on it. The third scenario involved pushing one device at a constant speed against the other device, which was initially at rest. The final scenario was similar to the third where one device pushed the other device, except this time it was at an increasing speed. For each scenario, the students were able to see a Force vs. Time graph for both IOLabs, and then asked to compare them.

The Lesson

The lesson was made up of 21 slides. The introductory slides were tutorials on how to use the IOLab devices. The rest of the slides guided the students through the different scenarios described above. The three figures below are sample slides, showing what the basics of the lesson looked like.

FIGURE 1. Sample instructional slide on how to use the IOLab.

FIGURE 2. Slide showing how the graphs should look when one device is pushing the other device at an increasing speed.

FIGURE 3. Slide showing the forces acting on each device when the two devices are repeatedly collided.

Abstract

The Force Concept Inventory (FCI) is used at schools across the country as a tool to measure student conceptual understanding of Newtonian physics. One of the weaknesses commonly identified is in applications of Newton's Third Law. In this project, we utilized a recently-developed wireless data acquisition system, the IOLab, to attempt to rectify student misunderstandings regarding the Third Law. The subjects for this research came from calculus and algebra-based introductory physics courses. An assessment of the effectiveness of this teaching tool as well as a comparison between the two courses will be included.

IOLab

Developed by Mats Selen and the PER group at the University of Illinois, Urbana-Champaign, the IOLab, seen in Fig. 4, is a wireless data acquisition system which interfaces with a PC/Mac using a USB dongle from up to 100 ft away. It is small (3 cm x 7.5 cm x 13 cm) and light (less than 200 g), which makes it highly portable. The most recent version of the IOLab contains more than twenty sensors or inputs, including a 3D accelerometer, a 3D magnetometer, a 3D gyroscope, wheels which record position, velocity, and acceleration, a force probe, and both analog and digital inputs. This device can be used for introductory and advanced physics courses.

FIGURE 4. IOLab device.

Interactive Scenarios

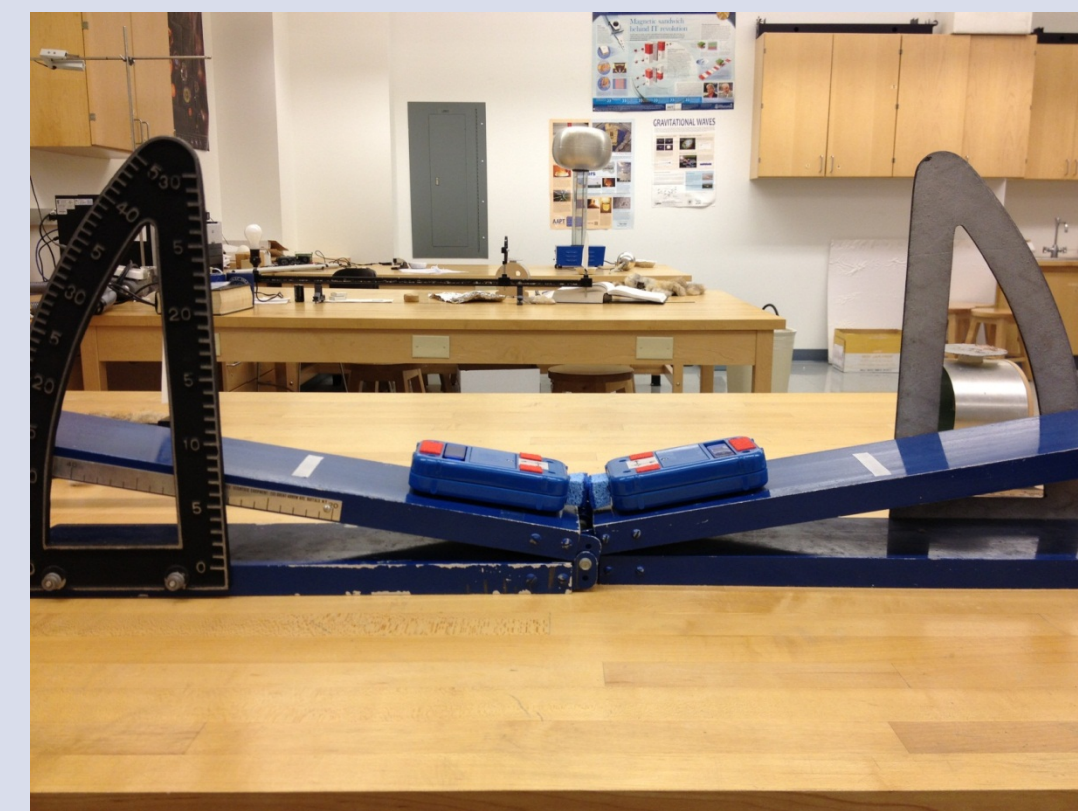The scenarios that were used are shown here in Figs 5, 6, and 7.

FIGURE 5. Scenario One - Both devices start on an incline, an equal distance apart, with the same mass, and collide at the bottom.
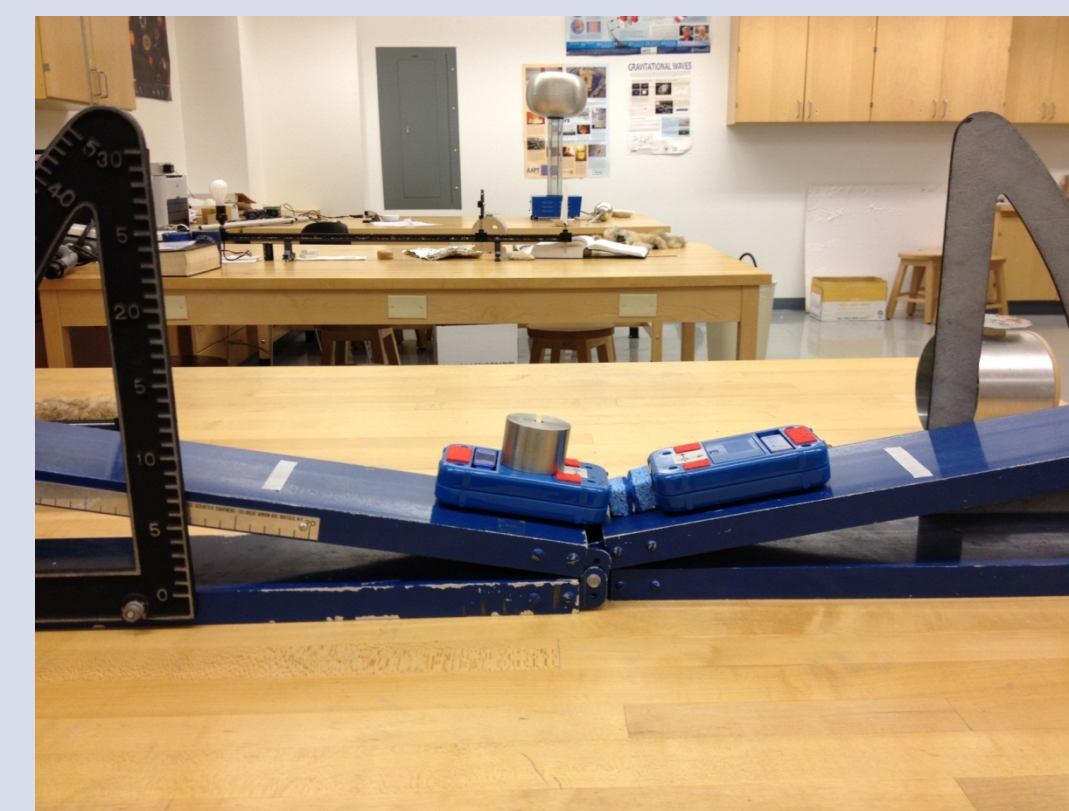

FIGURE 6. Scenario Two - Both devices start on an incline, an equal distance apart, with unequal masses, and collide at the bottom.
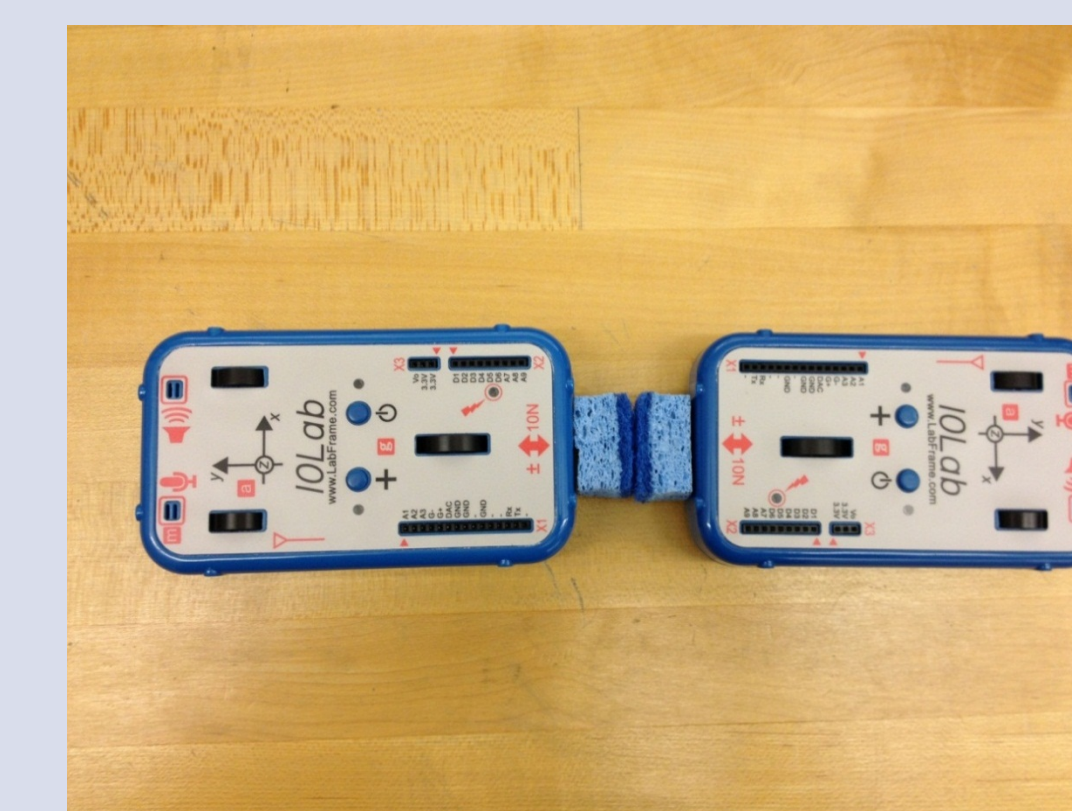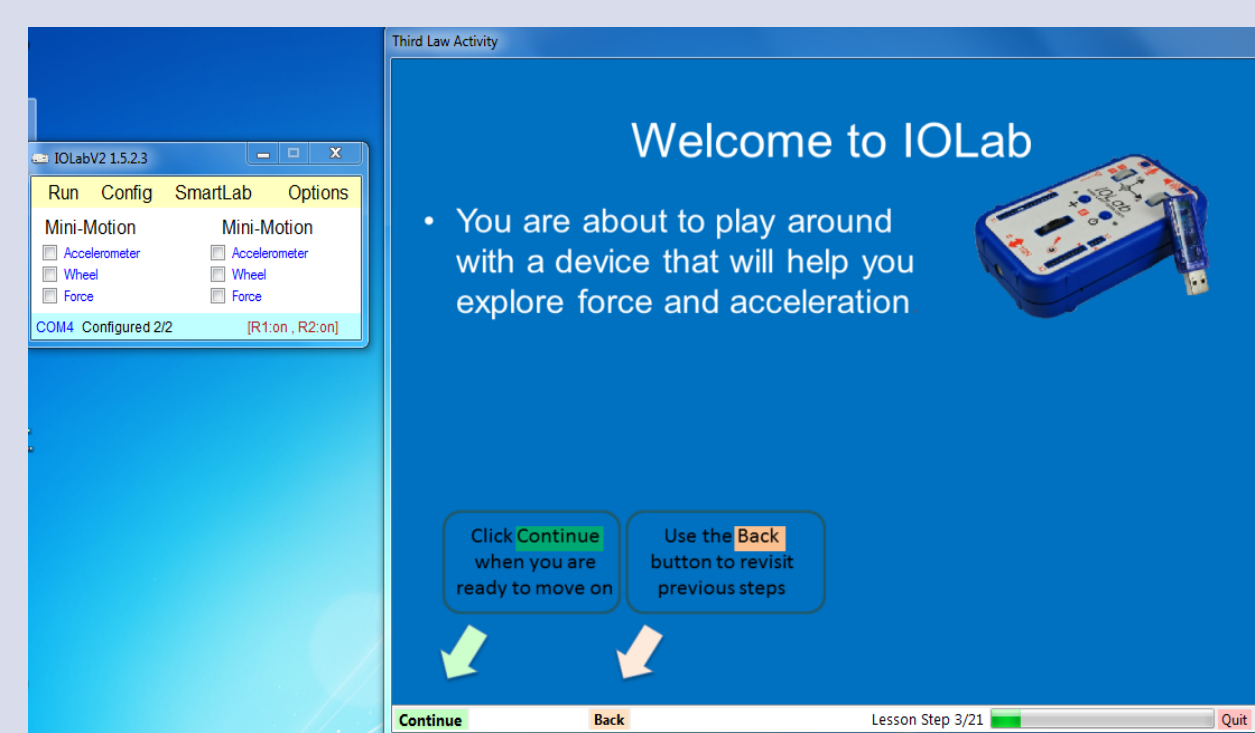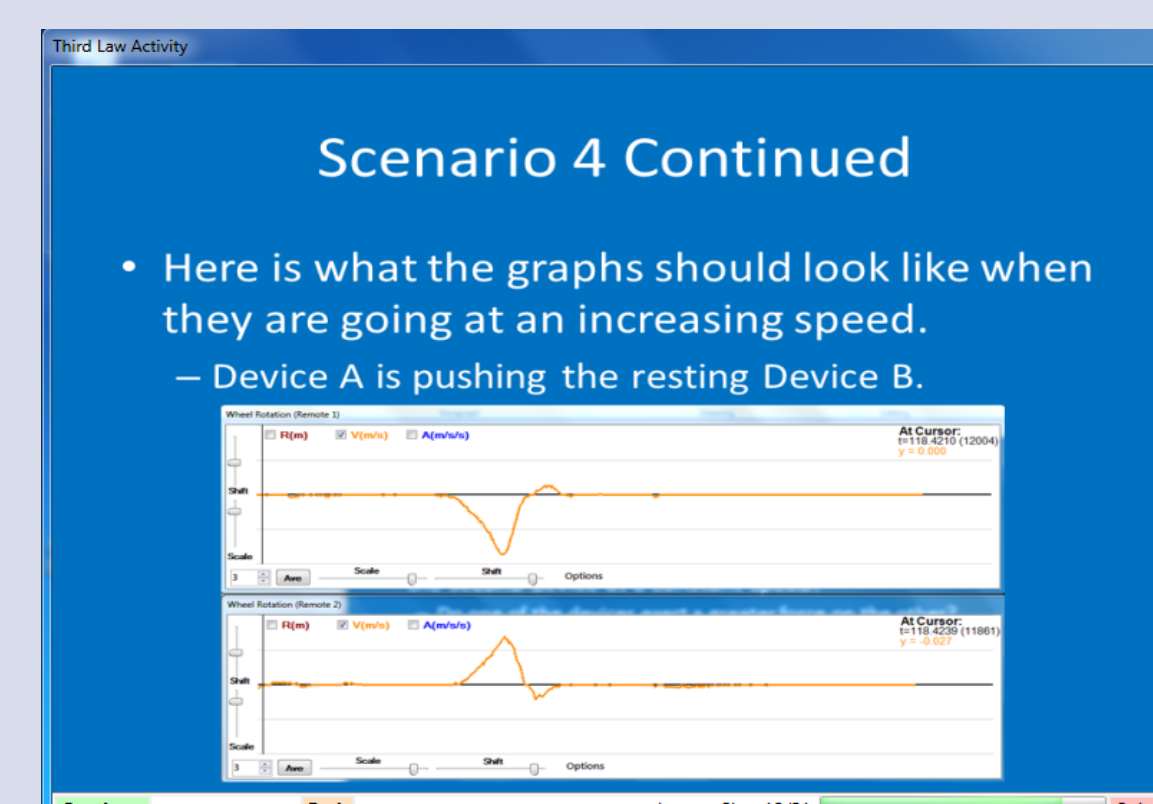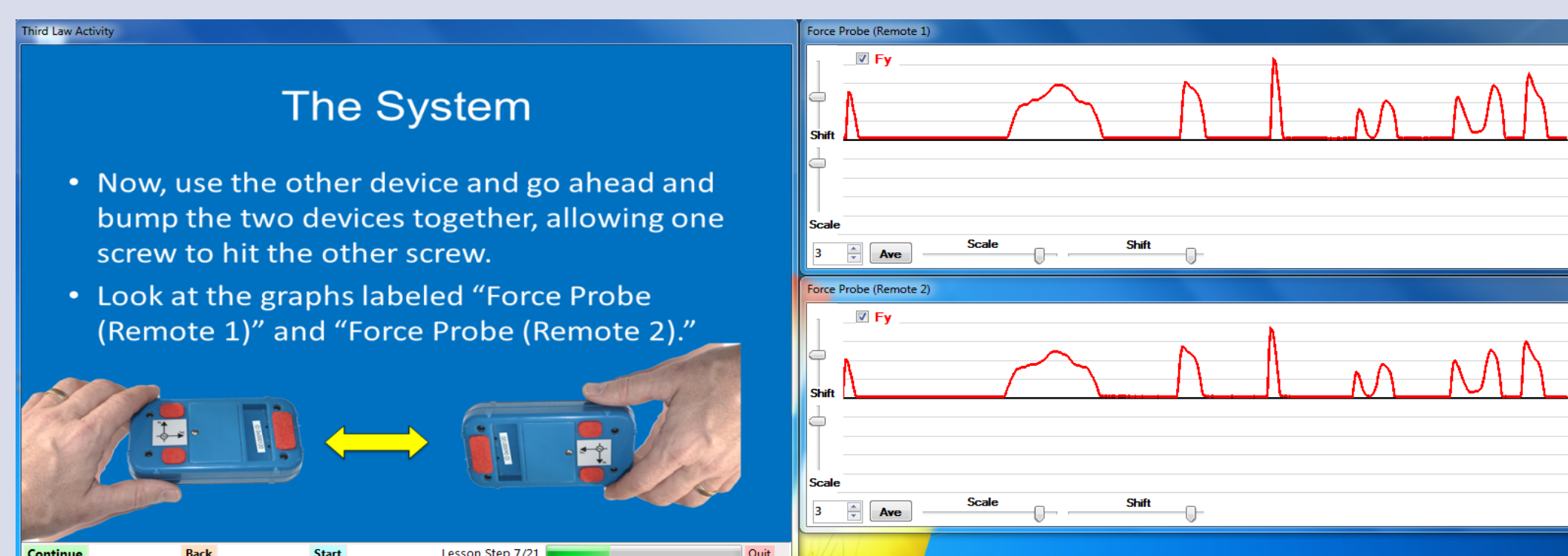

FIGURE 7. Scenarios Three and Four - Push one device against the other, starting at rest. In one scenario, they were moved at a constant speed, in the other, at an increasing speed.

Pre/Post-Test Questions

The pre-test and post-test each was comprised of four questions. The post-test questions consisted of numbers 4, 15, 16, and 28 from the FCI. Two of the four pre-test questions are shown below.

1. If a semi-truck and motor cycle have a head-on collision, upon which vehicle is the impact force greater?
    a. The semi-truck exerts a greater force on the motor cycle.
    b. The motor cycle exerts a greater force on the semi-truck.
    c. The forces exerted by the semi-truck and the motor cycle are the same.
    d. There are no forces exerted at all.

2. A child with a mass of 30 kg is on a swing set. The mother with mass 75 kg pushes the child on the swing set to get him going. How much force is being applied when the mother pushes the child on the swing?
    a. The mother is exerting more force on the child.
    b. The mother is exerting less force on the child.
    c. The mother exerts an equal force on the child.
    d. The mother and child exert no force.

Results

The majority of the students completing the experiment either performed the same on the pre/post-tests or improved. Thirteen out of the twenty-two participants performed the same on the pre-test and post-test. Eight out of the twenty-two participants improved, and one out of twenty-two participants performed worse.

The average score on the pre-test was 2.32, and the average score on the post-test was 2.73, a normalized gain (Pre-test – Post-test)/(4-Pretest) of 24.4%.

The graph below shows the pre- and post-test scores of each participant (1-22). The pre-test scores are in blue and the post-test scores are in white. The maximum number of points on the pre-test and post-test was 4 points.
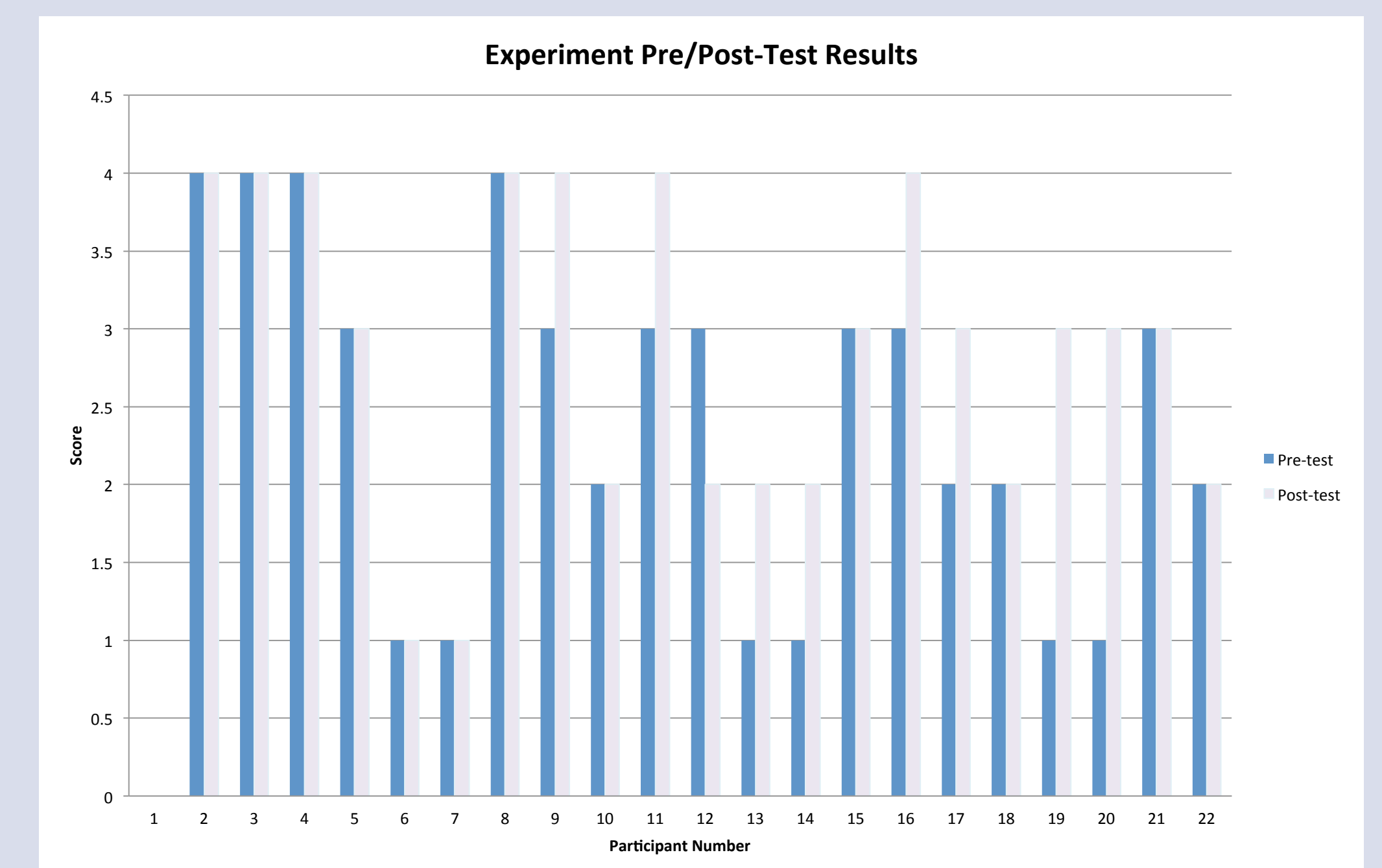

FIGURE 8. Pre- and Post-test results for each participant.

Conclusion and Future Testing

While the normalized gain for the subjects was 24.4%, the improvement is not statistically significant (p=0.26). If we remove the students who had all four questions correct on both the pre- and post-tests (students who could not improve), the results are slightly more significant, although not traditionally statistically so (p=0.16). The goal of this research was to help correct student misunderstandings with this law, and while anecdotally that may have happened, it is unclear from the data how much the students actually learned.

The timing of this experiment was not optimal for really testing the utility of using the IOLab to teach Newton's Third Law. All of the participants had completed a semester of physics, and may have already had a more rigid conception of the concepts. Also, participants not enrolled in a physics-related course would provide a control group for comparison. It might be interesting to see what range of people would be able to understand this concept of physics by just performing a simple experiment.

This experiment will be repeated during the upcoming year, with hopefully greater statistics and a control group of students who have not taken physics at the university level..

Acknowledgements