

# Adapting *RealTime Physics* for Distance Learning with the IOLab

**Erik Bodegom**, Portland State University, Portland, OR  
**Erik Jensen**, Chemeketa Community College, Salem, OR  
**David Sokoloff**, University of Oregon, Eugene, OR

The IOLab is a versatile and inexpensive data acquisition device in a cart that can roll on its three wheels. It has numerous sensors for a variety of physical quantities. We adapted *RealTime Physics, Module 1: Mechanics* active learning labs for use with the IOLab. We tested these labs both on campus and with distance learners at Portland State University and Chemeketa Community College for three years, consistently obtaining significant conceptual learning gains on the Force and Motion Conceptual Evaluation (FMCE).

Student attitudes towards the labs, the device, and distance learning—as measured by post-course evaluations—were generally very positive.



Fig. 1. The IOLab, an inexpensive data acquisition device in a cart that can roll on its three wheels.

## Introduction

Distance higher education continues to grow<sup>1</sup> in spite of both flat enrollment in higher education overall<sup>2</sup> and scandals<sup>3</sup> at for-profit universities. But science fields, especially physics, have been slow to adapt to demand,<sup>4</sup> often based on the perceived difficulty of delivering labs effectively and safely at a distance.

The 2014 “AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum”<sup>5</sup> include “constructing knowledge” as a desirable learning outcome. In spite of the development of online simulations and activities, it is still important for distance learning students to have an authentic laboratory experience in which they physically manipulate objects and actively use their observations to create or modify their conceptual models of the physical world. Recent advances in low-cost sensors and data analysis software make it feasible to offer physics labs in the context of an online or distance course.

But the solution to this problem requires more than technology. Recent research suggests that “traditional” lab experiences do not meaningfully impact student learning.<sup>6,7</sup> It should be noted, however, that this research did not include studio courses or courses implementing *RealTime Physics (RTP)*<sup>8</sup> as their lab component. In fact, it has been well documented that *RTP*—a research-validated, active learning lab curriculum—can guide students to consider and modify their

conceptual understandings.<sup>8</sup> While *RTP* has been demonstrated to be effective in class, it cannot easily be used in distance learning due to the cost, size, and complexity of the computer-based lab equipment. For this project we proposed the combination of the inexpensive IOLab device with the *RTP* curriculum as a solution to the need for research-validated distance learning mechanics labs.

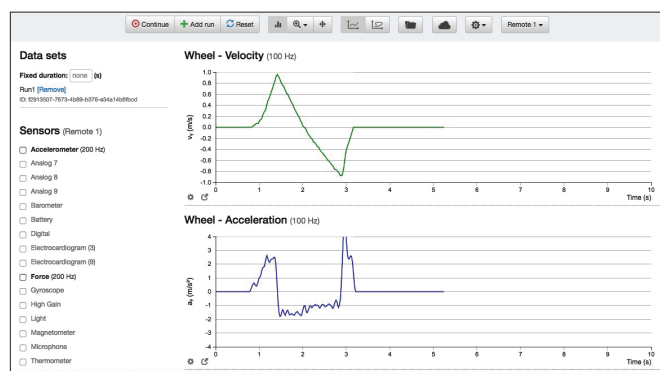


Fig. 2. Graphs of velocity vs. time and acceleration vs. time collected by the IOLab encoder for motion up and back down a smooth inclined ramp.

## The IOLab and IOLab software

The low cost and versatility of the IOLab<sup>9</sup> make it attractive for distance learning applications. It is a versatile data acquisition device that is self-contained in a cart (see Fig. 1). Its motion on its wheels is detected by an optical encoder, allowing measurement of motion quantities. It has numerous sensors for a variety of physical quantities, including a force sensor. This makes it ideal for examining its motion under a variety of conditions, and for exploring Newton’s laws of motion. Figure 2 shows graphs generated by the IOLab rolling up and back down an inclined ramp.

The basic IOLab software—that is free with the hardware—allows users to choose both the sensors to be activated and features of the graphs to be collected (such as axis limits). It also allows simple data analysis such as statistics and curve fitting. Lesson Player, a component of the IOLab software, allows these settings to be selected in advance of data collection (although students can still change them after data collection if this displays the data more clearly). With Lesson Player, instructions, questions, and answer boxes are displayed on one half of the screen while collected graphs are displayed on the other half in real time (see Fig. 3). Also, with Lesson Player, students can complete and submit their work electronically. These features are all well suited for our adaptation of *RTP* for

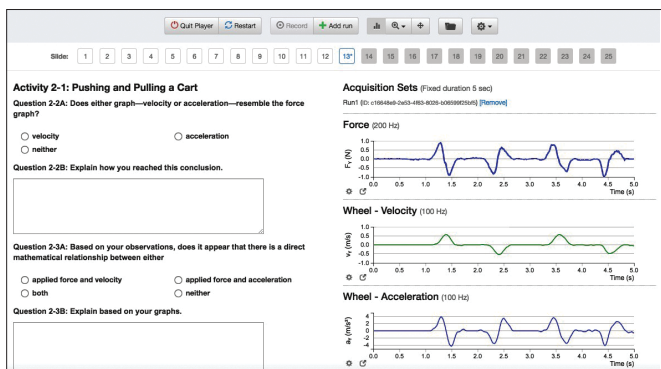


Fig. 3. An example of the appearance of a slide from Lab 4 as displayed with Lesson Player.

Table I. Active learning labs in mechanics developed for use with IOLab.

Lab 1. Introduction to IOLab
Lab 2. Introduction to Motion
Lab 3. Changing Motion
Lab 4. Force and Motion
Lab 5. More About Newton's Laws
Lab 6. Impulse and Momentum
Lab 7. Newton's Third Law and Conservation of Momentum
Lab 8. Two-Dimensional Motion
Lab 9. Work and Energy

distance learning. Other “smart carts” have become available during the timeline of this project.<sup>10</sup> It was not within the scope of this project to compare the capabilities of these. The PocketLab,<sup>11</sup> although quite capable, does not include an encoder or force sensor.

### RealTime Physics pedagogy

Beginning in 1992 a set of *RTP* labs was developed with funding from the National Science Foundation. Four lab guides (modules) are currently published by John Wiley and Sons.<sup>12</sup> Each lab guide includes activities for use in a series of related lab sessions that span an entire quarter or semester for the lab accompanying either the calculus-based or algebra-based introductory physics course. Lab activities and homework assignments are integrated so that they build on learning that has occurred during the previous lab session and prepare students for activities in the next session. The major goals of the *RTP* curriculum are to help students: (1) acquire an understanding of a set of related physics concepts; (2) experience the physical world directly by using computer-based tools for real-time data collection, display, and analysis; (3) develop traditional laboratory skills; and (4) master topics covered in lectures and readings using a combination of conceptual activities and quantitative experiments.

In order to achieve these goals, a set of design principles was developed for the laboratory guides. Lab activities (1) are sequenced and build on each other, (2) invite students to construct physical models based on their observations, (3) incorporate a learning cycle of prediction, observation, and

comparison to help students to modify their common, naive conceptions, and to understand powerful general physics principles, (4) provide opportunities for students to discuss ideas and findings in small groups of two to four, (5) include a pre-lab assignment to prepare for lab and a homework assignment designed to reinforce critical concepts and skills.

### The IOLab Distance Learning Laboratory project

Starting in 2015, with support from the National Science Foundation,<sup>13</sup> we developed a series of mechanics labs for use with the IOLab in distance learning environments. These labs are mostly based on *RTP*, as adapted for the particular characteristics of the IOLab and software.

A recent paper has documented that physics education research is typically done with students who are “better prepared mathematically and are less diverse than the overall physics student population.”<sup>14</sup> We avoided this issue by testing the labs we developed for IOLab at Portland State University (PSU), an urban university with an 89% acceptance rate,<sup>15</sup> and at Chemeketa, an open-enrollment community college in the process of obtaining federal designation as an Hispanic-Serving Institution.

At PSU, all students were enrolled in a campus-based traditional lecture (either calculus or algebra-based) and experienced our labs either on campus (in a normal laboratory room) or in distance learning mode. At Chemeketa, all students were enrolled in an active learning,<sup>17</sup> algebra-based course. Chemeketa students were either entirely campus based or entirely in distance learning mode.<sup>18</sup> We loaned an IOLab to each distance learning student. While the IOLab includes a few accessories from the manufacturer such as springs and hooks, we provided an additional kit with a protractor, a bouncy ball, clay, fishing line, weights, and a few other items for an additional cost to us of about \$10 per student.

Table I lists the titles of the final versions of the nine labs that we developed. (Note that Lab 8 also makes use of video analysis<sup>19</sup> to examine the projectile motion of a thrown ball.) Control groups at both institutions completed traditional labs: on-campus at PSU and in distance learning mode at Chemeketa with traditional lab kits.<sup>20</sup>

As part of the project, we tested IOLab active learning labs during five rounds at each institution.<sup>21</sup> Each of these rounds afforded us opportunities to observe campus-based students in class as they worked through the labs, to examine the graphs all groups collected and the lab sheets they turned in, and to assess their understanding of mechanics concepts. This was an iterative process during which we revised the labs, hardware, and software according to what we learned. Among the lessons we learned from this process are:

- The lack of bearings in the low-cost wheels of the IOLab results in significant friction. For example, the acceleration of the IOLab while rolling up an inclined ramp is noticeably different from that rolling down. (This can be seen in Fig. 2 in the change in slope of the

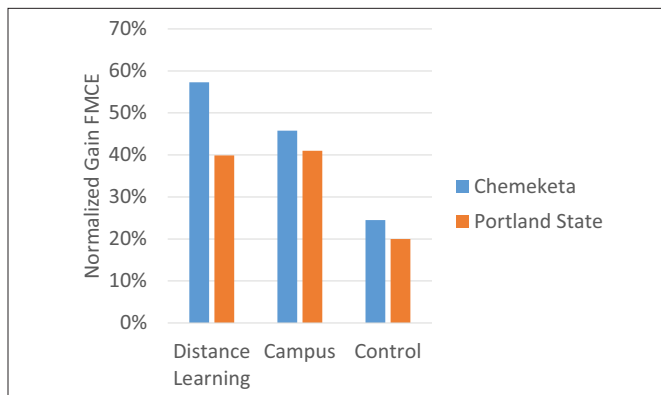
velocity-time graph and change in acceleration on the acceleration-time graph at approximately 2 s, when the IOLab reached its highest point along the ramp.) This complicates initial learning of kinematics and Newton's laws. It is our opinion that the manufacturer should install bearings on the IOLab.

- The significant friction makes it more difficult to do the very effective *RTP* activities that directly lead to an understanding of Newton's first law. We struggled with this, and in the end had to use hanging masses to compensate for the friction.
- The level of noise in the electronic signals from the force sensor sometimes makes it difficult to see the desired experimental results.
- Because we wanted to make these labs low cost, we provided each student with *only one* IOLab. In order to incorporate the research-validated Newton's third law collision and conservation of momentum activities from *RTP* into Lab 7, we incorporated videos of two IOLabs.<sup>22</sup>
- Like all accelerometers, the IOLab measures proper acceleration (acceleration relative to free fall), not coordinate acceleration (acceleration with respect to the lab). This can cause conceptual difficulties for beginning students. We used accelerations calculated from the wheel encoder for this reason, and also because measurements from the encoder are pedagogically richer, since they explicitly include both velocity-time and acceleration-time graphs.
- Technical support for some distance learning students proved to be challenging, especially at Chemeketa. Students had a variety of computer operating systems and hardware, and they had a wide range of computer skills. (For example, some lacked the ability to move files from one folder to another.) At Chemeketa, we posted instructions and videos showing how to install and use the software. We also used an online discussion board where students could post questions and screen captures when they encountered problems. At PSU, we met with students in person at the beginning of the term to issue equipment and install software. Even with considerable effort to help students, a few chose to drop rather than work to overcome these issues. But the overall dropout rate was comparable to regular classes at PSU and Chemeketa.

## Conceptual learning as measured with the FMCE

We measured learning of concepts related to kinematics and Newton's laws with a shortened (34-question) version of the Force and Motion Conceptual Evaluation (FMCE).<sup>23,24</sup> Figure 4 compares the normalized gains<sup>25</sup> for the most recent tests at both PSU and Chemeketa (fall 2017), after several years of refining the labs (as described above).

The randomly assigned control group at PSU<sup>26</sup> only completed the posttest. We calculated the normalized gain for



**Fig. 4.** Normalized learning gains on the shortened, 34-question Force and Motion Conceptual Evaluation for students at Chemeketa and PSU during fall 2017. Group sizes for Chemeketa were Distance  $N=30$ , Campus  $N=26$ , Control  $N=25$ . For PSU, Distance  $N=41$ , Campus  $N=33$ , Control  $N=69$ .

this control group assuming that their pretest score was the same as the average of the PSU IOLab group. (From previous rounds, we knew that the pretest scores do not differ substantially for the various groups at PSU.) The Chemeketa controls completed both the pre- and posttest, and their normalized gains were calculated directly.

The conceptual learning gains by the IOLab groups are consistently significantly better than the control groups that did traditional labs. Note that all students at PSU were experiencing traditional lectures from several different lecturers whom the students selected randomly. Therefore, the higher learning gains for the IOLab groups can be attributed to their IOLab experience. The distance learning students at Chemeketa experienced "lecture" material enhanced by active learning strategies,<sup>15</sup> which probably accounts for their somewhat higher overall learning gains. While these results are not as good as those achieved with *RTP*,<sup>8</sup> we conclude that our adaptation of *RTP* for the IOLab consistently and measurably improves student conceptual understanding for both distance learning and campus-based students.

## Evaluation of student attitudes

The students experiencing the labs, IOLab device, and IOLab software had generally favorable attitudes towards their experience, as indicated by their responses on end-of-term lab course evaluations. For example, Table II shows the average response (5 = strongly agree, . . . 1 = strongly disagree) to a number of statements describing the experience of the PSU students who did the labs in distance learning mode during fall 2017. The ratings of statements 1 and 2 indicate that the students were comfortable carrying out the experiments on their own, at home, while statements 4-7 indicate a positive feeling about the learning environment established by these labs. The results on statement 3 (5 = learned much more, . . . 1 = learned a lot less) indicate a generally positive perception of the learning experience with the IOLabs.

Although we did not set out to change attitudes towards experimental physics, we did check if any changes occurred. We had students respond to portions of the E-CLASS<sup>27</sup> both pre and post in fall term 2017. We did not find any change in

**Table II. Average response on end-of-term evaluations by distance students at PSU, fall 2017, N=41.**

1	Knowing there are 10s of very short YouTube videos online, explaining some of the more confusing parts of using IOLab and software, I could have done these labs at home.	4.4
2	Compare your perception of learning using this style of lab instructions to the lab instructions you have used in other labs.	3.6
3	These labs helped me with my conceptual understanding of physics.	4.2
4	I have gained a greater insight into the nature of the physical world.	4.1
5	I have learned useful concepts from the laboratory course.	4.2
6	The laboratory course added to my understanding of the lectures.	3.9

student strategies, habits of mind, or attitudes towards experimental physics based on this metric.<sup>28</sup>

## Implementation observations from the instructors

From the instructor's perspective there are a number of advantages to the IOLab-based experiments:

- There were few conceptual questions from distance learning students. When they contacted us, it usually concerned a technical issue, not difficulty in understanding the physics.
- The labs do a good job of connecting real-world experiences to mathematical representations.
- Grading is easier compared to standard labs. There is only one file for each lab, and all students submit essentially the same format file.

For campus-based labs:

- It is easier to demonstrate concepts to students with the IOLab equipment.
- Set up and tear down is much easier compared with most standard, traditional labs.
- There is less time needed to explain how the lab equipment works and, therefore, more time for student work and discussion.
- If students miss a class because of illness, etc., they can borrow an IOLab to make it up. (Of course, providing accommodations for excused absences is one big benefit of distance learning classes, and in several instances made it possible for students to take the course.)

## Conclusions

We have established that research-validated introductory physics labs can be delivered effectively in distance learning mode at low cost using IOLab. While the goals of the introductory lab can certainly be debated, they should be both explicit and measurable. We consider conceptual learning in lab to be important and achievable, and we urge the physics edu-

cation community to embrace active learning, research-validated labs. The labs we developed for use with the IOLab are a viable, inexpensive option.

## Acknowledgments

We would like to thank Dr. Mats Selen and his colleagues at the University of Illinois and Dr. Geoffroy Piroux at B12 Consulting for development of the IOLab and software. We also thank Dr. Selen for providing IOLabs for our pilot studies, and for listening to the many suggestions we made for improving the IOLab software, and Dr. Piroux for rapidly implementing most of these suggestions. We thank Dr. Kathleen Harper for her guidance as our evaluator, the NSF for financial support of our work, John Wiley and Sons for their permission to adapt RTP, and MacMillan, the manufacturer and distributor of the IOLab. We also thank Chemeketa students Paul Ivanov, Nicholas Jones, and Benjamin Steele and PSU teaching assistants Mike DeArmond and Caitlin Kepple for their contributions to this project.

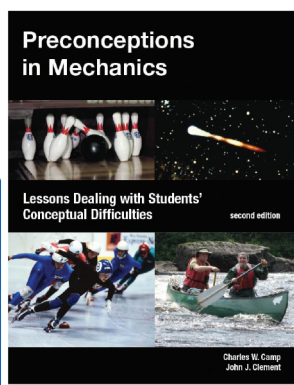
## References

1. Julia E. Seaman, I. Elaine Allen, and Jeff Seaman, "Tracking distance education in the United States," <https://onlinelearning-survey.com/reports/gradeincrease.pdf>, p. 11.
2. Ibid., p. 7.
3. See, for example "Panel votes against accreditor of for-profit colleges," <https://usnews.com/news/business/articles/2016-06-23/big-accreditor-of-for-profit-colleges-could-lose-authority>.
4. A. M. Reagan, "Online introductory physics labs: Status and methods," *J. Washington Acad. Sci.* 31-46 (Spring 2012).
5. "AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum," [https://aapt.org/Resources/upload/LabGuidelinesDocument\\_EBendorsed\\_nov10.pdf](https://aapt.org/Resources/upload/LabGuidelinesDocument_EBendorsed_nov10.pdf).
6. Carl Wieman and N. G. Holmes, "Measuring the impact of an instructional laboratory on the learning of introductory physics," *Am. J. Phys.* 83, 972 (Nov. 2015).
7. Natasha G. Holmes and Carl E. Wieman, "Introductory physics labs: We can do better," *Phys. Today* 71 (1), 38 (Jan. 2018).
8. David R. Sokoloff, Ronald K. Thornton, and Priscilla W. Laws, "RealTime Physics: Active Learning Labs Transforming the Introductory Laboratory," *Eur. J. Phys.* 28, S83-S94 (2007).
9. IOLab Wireless Lab System, <https://iolab.science>. For more information and the current price, see <https://www.macmillanlearning.com/catalog/preview/iolab>.
10. See, for example, the PASCO Wireless Smart Cart, <https://www.pasco.com/prodCompare/smart-cart/index.cfm> and the Vernier Go Direct Sensor Cart, <https://www.vernier.com/products/sensors/motion-encoders/gdx-cart-g/>.
11. See <https://www.thepocketlab.com/>.
12. David R. Sokoloff, Ronald K. Thornton, and Priscilla W. Laws, *RealTime Physics: Active Learning Laboratories, Module 1: Mechanics, Module 2: Heat and Thermodynamics, Module 3: Electricity and Magnetism, and Module 4: Light and Optics*, 3rd ed. (Wiley, Hoboken, NJ, 2011).
13. Funded under U.S. National Science Foundation grant DUE - 1505086, July 1, 2015-June 30, 2018.
14. Stephen Kanim and Ximena C. Cid, "The demographics of physics education research," <https://arxiv.org/abs/1710.02598>.
15. "Best Colleges, U.S. News, Portland State University," <https://usnews.com/best-colleges/portland-state-3216>.

# Look What's in The Physics Store!

## Preconceptions in Mechanics

This second edition of Charles Camp and John J. Clement's book contains a set of 24 innovative lessons and laboratories in mechanics for high school physics classrooms that was developed by a team of teachers and science education researchers. Research has shown that certain student preconceptions conflict with current physical theories and seem to resist change when using traditional instructional techniques. This book provides a set of lessons that are aimed specifically at these particularly troublesome areas: Normal Forces, Friction, Newton's Third Law, Relative Motion, Gravity, Inertia, and Tension. The lessons can be used to supplement any course that includes mechanics. Each unit contains detailed step-by-step lesson plans, homework and test problems, as well as background information on common student misconceptions, an overall integrated teaching strategy, and key aspects of the targeted core concepts. A CD of all duplication materials is included.



Members: \$28  
Non-Members: \$30



Order yours now at  
[www.aapt.org/store](http://www.aapt.org/store)

- Cheryl P. Rose, "Student diversity a notable asset for Chemeketa Community College," [https://blog.oregonlive.com/education\\_plus/2016/05/student\\_diversity\\_a\\_notable\\_as.html](https://blog.oregonlive.com/education_plus/2016/05/student_diversity_a_notable_as.html).
- Influences include E. Mazur (*Peer Instruction*), L. McDermott (*Tutorials in Introductory Physics*), R. Knight (*Five Easy Lessons*), and D. Pritchard (*Mastering Physics*).
- Erik Jensen, "Welcome to PH201-203 Online," <https://sites.google.com/chemeketa.edu/erikjensen/ph201-203>.
- Tracker, a free video analysis and modeling tool, <https://physlets.org/tracker/>.
- Erik Jensen, "PH201-203 Lab Kits," <http://faculty.chemeketa.edu/ejensen6/labkits.html>.
- Fall 2015 at PSU, winter 2016 at Chemeketa, summer and fall 2016 at PSU and Chemeketa, and summer and fall 2017 at PSU and Chemeketa.
- See collision video example, <https://youtube.com/watch?v=Z-7wRSi52a0>.
- Ronald K. Thornton and David R. Sokoloff, "Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the evaluation of active learning laboratory and lecture curricula," *Am. J. Phys.* **66**, 338–352 (April 1998).
- We shortened the FMCE in order to enlist the cooperation of those who were teaching the control groups. The version we used included questions 1-21, 30-38, and 40-43.
- Normalized gain  $\langle g \rangle$  is defined by  $\langle g \rangle = 100\% \times [(Post.score - Pre.score)] / [(Max. possible score - Pre.score)]$ .
- Students could opt out of either version of the lab as control groups were taught at the same times as the IOLab groups, but none chose to do so.
- H. Lewandowski, "E-CLASS: Colorado Learning Attitudes About Science Survey for Experimental Physics," <https://jila.colorado.edu/lewandowski/research/e-class-colorado-learning-attitudes-about-science-survey-experimental-physics>.
- Bethany R. Wilcox and H. J. Lewandowski, "Open-ended labs can be designed with gains on the E-CLASS as an explicit goal," *Phys. Rev. ST Phys. Educ. Res.* **12**, 020132 (2016).

**David R. Sokoloff** is a professor of physics at the University of Oregon, was president of AAPT in 2011, the Robert A. Millikan medal winner in 2007, and is an AAPT fellow.

[sokoloff@uoregon.edu](mailto:sokoloff@uoregon.edu)

**Erik Jensen** (MS Physics, Oregon State University) teaches both campus-based and online physics at Chemeketa Community College in Salem, OR. He was an early developer of online physics courses in 2005. His current interest is the "lightboard," which he is using for both instructional videos and online office hours. His hobbies include soccer and obstacle course racing.

[erik.jensen@chemeketa.edu](mailto:erik.jensen@chemeketa.edu)

**Erik Bodegom** is a professor at Portland State University; he served as the host to the annual summer meeting of the American Association of Physics Teachers in 2010. For 18 years he was department chair and during this time the number of physics BS degrees at PSU grew to be ranked in the top 15% of physics departments in the country.

[Bodegom@pdx.edu](mailto:Bodegom@pdx.edu)