Innovations in teaching of the Physics and Astronomy laboratories

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The laboratory section of the introductory Physics course provides students with the initial laboratory skills and practical experience that would be further honed by higher level courses. The quality of that experience as well as the practical applicability and variety of the lab skills are important. Since the start of the current pandemic and restrictions on lab sessions (later replaced with room limitation of number of students attending), a new approach had to be found to provide a complete lab experience to students. This paper describes the new experiments and the innovative methodology that were introduced with the use of the Tracker software in the introductory Physics I laboratory. This new methodology has not only expanded the number of possible experiments for the laboratory, but also has provided students with the ability to conduct some of the simple experiments at home using common household items, thus offering the exciting experience to students and the backup option to instructors in the case of further restrictions to attendance of lab facilities by students.

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1. Introduction

From the times of the lockdown due to the COIVD19 pandemic, the online component has become increasingly popular among the students and has been added to many courses. Examples include online exams, quizzes, video materials and so on. However, can such component be added to the introductory physics laboratory while at the same time enhancing the overall student experience and extending the depth of the material learned? After the return of in-person classes with limited room capacity at Clayton University, we had to use the alternating schedule with a half of the class attending, rotating every other week. Thus, the methodology and the approach had to be adjusted accordingly. An additional factor that has influenced the creation of this approach was the previous research that shows 'labs are more effective when their goal is to teach experimental practices rather than to reinforce classroom instruction...' [1]. An introduction of the cohesive lab experience and lab skills training over the semester program has followed.

2. Analysis of video data using the Tracker tool

Tracker software is a free cross-platform software package that provides capabilities for the object tracking in the video file. It can also work with images to measure distances, angles, sizes of objects. It can also work with images containing spectra and provide their analysis as well.

Formally, as stated by [2], the 'Tracker is a free video analysis and modeling tool built on the Open Source Physics (OSP) Java framework'. It contains multiple instruments that allow for the object tracking in video, data analysis and even modeling using kinematics of point masses. This new and easy-to-use tool has been introduced to our introductory physics labs. It provides the ability for students to use the video analysis of actual experiments to obtain the physical data or make simple experiments at home. The analysis can be done even using the external data from the computer sensors that was obtained in the lab. The initial test introduction of the Tracker tool for use in physics labs has been presented in previous work [3]. Brief details of the Tracker software features are highlighted here.

The Tracker main tools that are set up before the start of any analysis are shown in Figure 1. This screen allows to initialize the basic parameters such as: setting up the scale, aligning the axes, measuring angles and radius (not shown). After the completion of this initial setup, the user can choose the object to be tracked. For that a template needs to be selected from the current image. After this simple step, the tracking is automatically done by the software.

The tracking process results are displayed as a table and as a series of plots, up to three at a time. Data can be exported as the csv format file; import is also possible. A user can select the plot(s) to display and how many should be shown. A curve showing the relationship of two variables (that is, not only something vs. time, but also velocity vs. distance and so on) that can be displayed in this window can also be analyzed by opening the additional window as shown in Figure 2. From there user can select one of the pre-defined functions for the fit or define a custom one. Additionally, errors on the fit parameters are also displayed. Simple statistics such as mean and standard deviation can be found for the selected points from the plot or the data table.
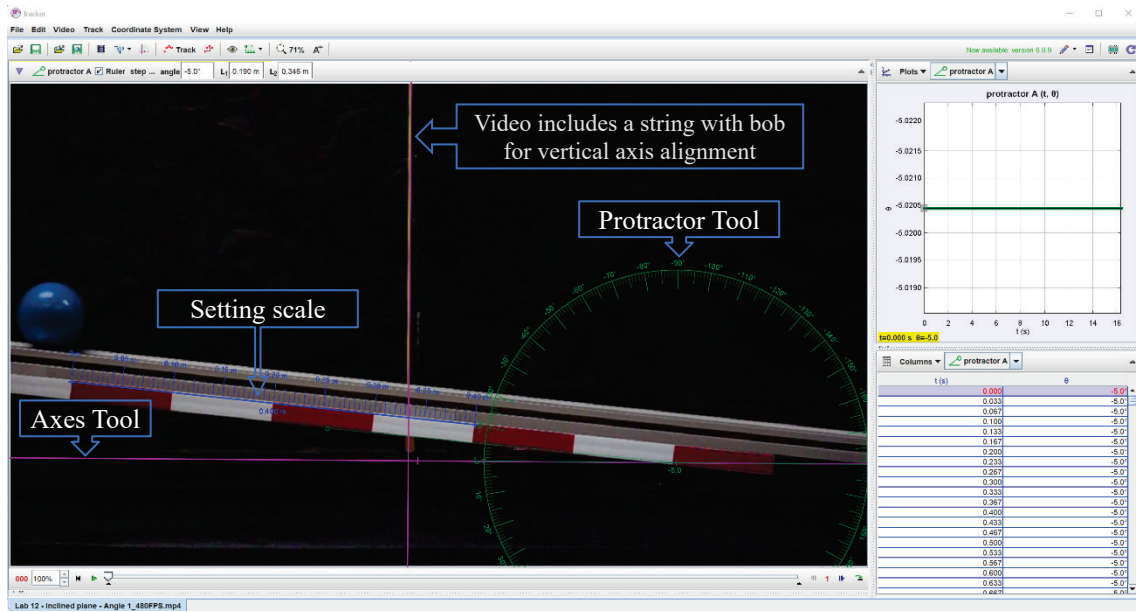
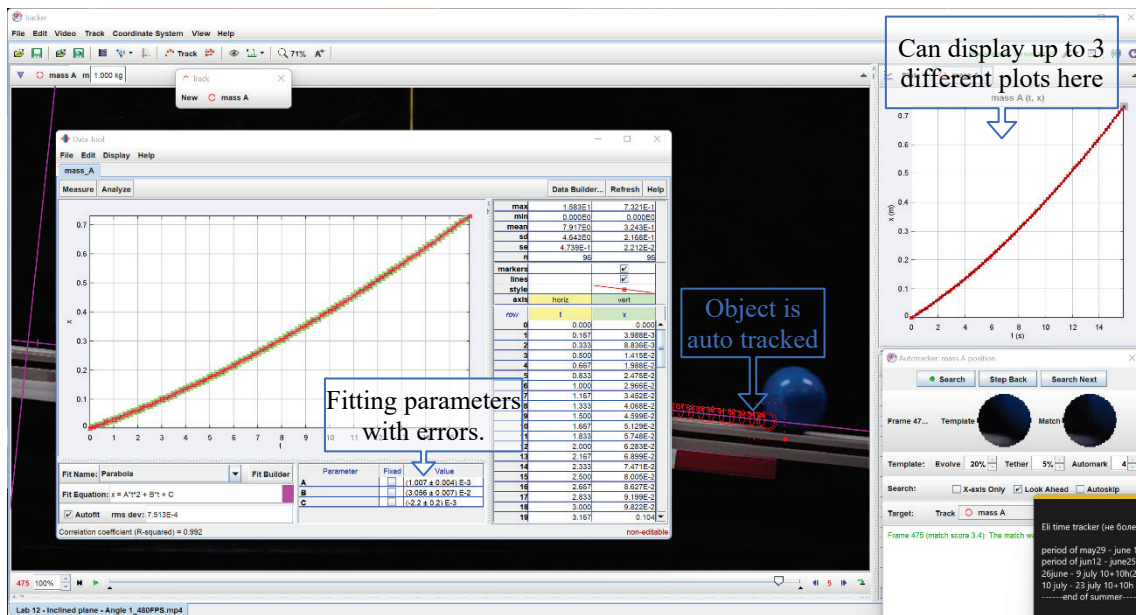*Figure 1: The Tracker main screen with main tools set up.*

Figure 2: Tracker screen with object autotracking. Analysis window with curve fitting results is shown.

3. A progression of topics for laboratory sessions experience

Table 1 shows currently implemented progression of the topics for the first semester of introductory physics laboratory at Clayton University. Material creation for the second semester is still in progress and will include the extension of the idea with things like a manual Gaussian fit in Excel[TM], basics of presentation creation, linear map, solving a system of linear equations and other ideas. The topics chosen teach the laboratory skills that will be equally useful for most of the student population that normally signs up for the introductory physics course, such as Chem, Bio, Math, Computer Science majors as well as students in the pre-engineering program.

In Table 1, odd numbered sessions are the online/Tracker-based labs. Introduction of material can partially overlap between the in-class and Tracker assignments since one half of students encounters Tracker assignments before the in-class ones. Under 'Excel' we assume any spreadsheet software with similar capabilities such as plotting, trendline and regression/histogram analysis.

Table 1: List of the progression of topics and experiment suggestion for each.

Session #	Skills introduced	Suggested experiment to match
0	Organizational questions, safety lecture / video / quiz	None. Occurs during the first week of classes, no material is covered yet
1	Lab report format and Tracker basics. Extensive video tutorial is provided	A simple assignment in Tracker with detailed instructions
2	Lab report format and Excel-based assignment. Video tutorial provided	A tutorial and assignment to bring the class to the same Excel level needed
3	Into the error analysis, systematic and statistical errors. Error propagation	Simple experiment to find the density of an object
4	Find systematic and statistical error in Tracker. Linear regression in Excel	Free fall experiment. A free-falling object was filmed using 960 pfs
5	Error propagation, plot of data vs model. Error bars. Measure angle in Tracker. Use of fitting tools in Tracker	Projectile motion experiment. Plot the expected range vs. angle and compare with 5 provided videos
6	Error propagation. Detailed plot, fit and χ^2/ndf to include error bars in Excel	Archimedes Law. Weigh 5 objects in water and in air, plot and find density
7	Use sensor data offline. Find and approximate the peak position and value. Analyze external data in Tracker	Forces of friction. The plot slope will be friction coefficient (two plots, for static and kinetic)
8	Use of computer-based sensor readout and calibration. Y and X error bars	Pressure in fluids. Take ratio of slopes to remove unknown calibration const.
9	A plot with multiple data series, analysis using a plot of residuals	Energy conservation. Analysis of a vertically oscillating mass on spring
10	Use wireless sensors. Find area under the curve. Compare slope error to slope value, convert χ^2 to p-value: for best fit and expected model, draw conclusions	Momentum and Impulse. Measure final velocity, mass, and force vs. time using wireless sensors on a cart. Use data to show momentum=impulse
11	Measure object radius in Tracker. Test on learned skills of using Tracker	Moment of Inertia. An object rolling down an incline, find I to study object
12	Non-linear effect study. In-class test lab (report is submitted by lab end)	Simple pendulum. Empirically study period vs. angle, show quadratic trend

4. Students' survey on Tracker experience for online labs

Before starting this full integration, a quick survey has been performed after the initial test introduction of the Tracker [3]. After the first semester of adopting the new topic progression with the Tracker at Clayton University, the survey with same questions has been repeated. The only

difference between them is that the initial survey had free response questions and the categories were produced from the students' answers. Second time, the same categories were turned into questions so that the new results can be directly compared with the previous ones. The survey was included as part of the last lab meeting so that all students would provide their opinion (while it was anonymous, we could see the number of responses before the end of the class). Overall, 22 responses were received.
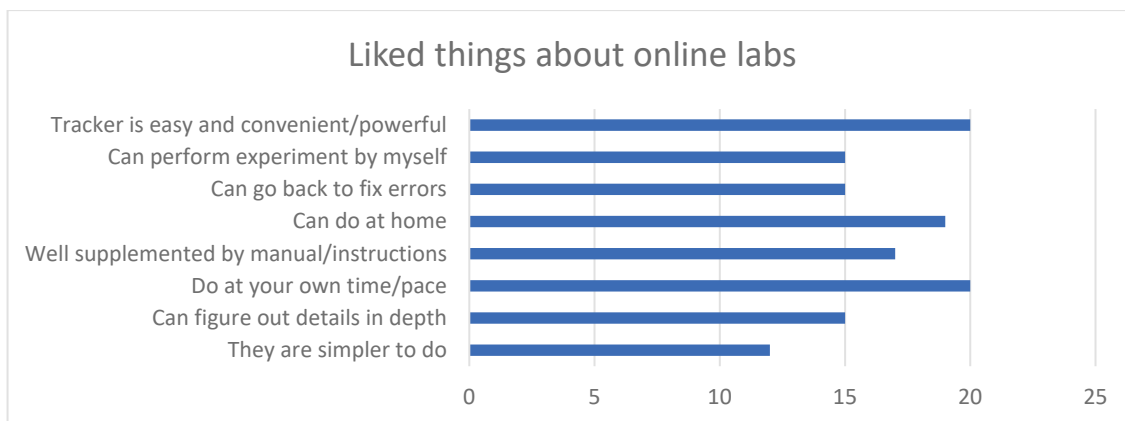

Figure 3:Survey results – what students liked about the online labs and Tracker.

The student responses to the 'liked' section about the Tracker labs are shown in Figure 3. When comparing with the previous survey results, we see that about the same proportion of responses remains, showing the successful implementation of the whole semester program as compared to the small pilot program attempted last year.

From Figure 4 we can see that a significantly lower number of students has responded to the 'dislike' questions section. Most notable is the reduction in the number of students who thought that feedback and answers to questions were slow to obtain due to the faculty effort and the fact that during pilot program the resources were not fully committed to Tracker, and this time around we were teaching a full summer semester using this new approach. We also believe that it's the summer semester that makes it harder for students to work in a group while doing the Tracker labs as students typically don't stay in dorms during the summer.
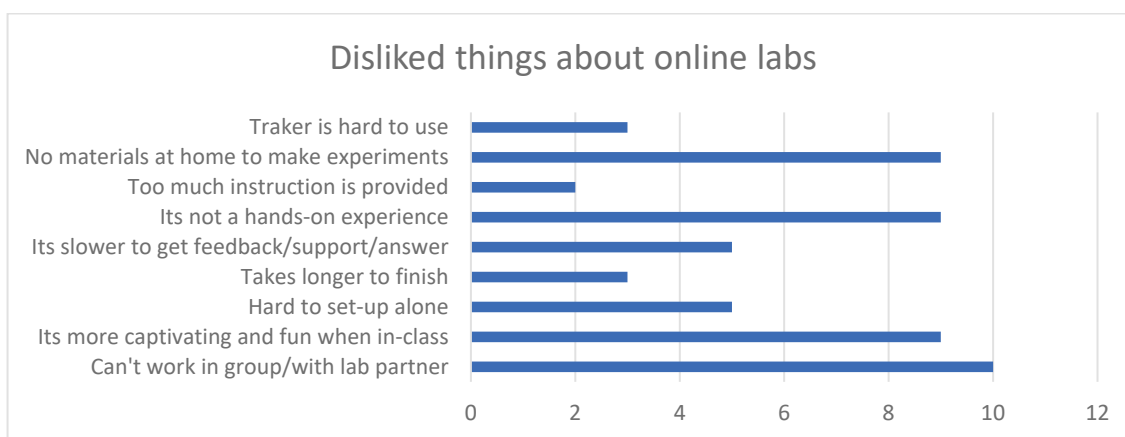

Figure 4: Survey results – what students disliked about the online labs and Tracker.

5. Conclusion

The initial experience from the pilot program using Tracker has shown that the online labs are generally liked by the students and are sometimes preferred over the in-class ones. The re-write of the first semester of introductory physics labs has been completed based on that initial experience and new material was introduced for the summer'22 semester at Clayton University. The goal to move the 50% of all labs to use Tracker (with ability to be the online labs) was successfully implemented. High quality videos of 480 to 960 frames per second were produced for these labs; the lab manuals were completely redone and adopted to the new progression of topics. The end of semester survey shows that the students like the Tracker labs the same as compared to previous survey, and that we successfully reduced some of the dislikes that were reported previously.

Acknowledgement

References

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[2] Wieman, N. H. (2018). *Introductory physics labs: We can do better. Physics Today*, **71**, 1-38. [DOI: https://doi.org/10.1063/PT.3.3816]

[3] Dmitriy Beznosko, Tatiana Krivosheev, Alexander Iakovlev, *Transformation of the Physics and Astronomy courses*, in proceedings of *37th International Cosmic Ray Conference*, PoS(ICRC2021)1363, https://pos.sissa.it/395/1363/pdf