Scalable Laboratory Experimentation using iLabs - the Digital Twins for Experiments

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Abstract: We propose using "iLabs," which relies on the digitalization of an experiment and a virtual display with photographs, as a solution to overcome the lack of scalability of realistic online experimentation and facilitate educational conversations.

1. The case for scalable online experiments

Online education's most societally-impactful promise is its ability to lower the barrier to entry for learning. While most aspects of online education — such as streaming lectures and facilitating testing — are highly scalable, laboratory education is not. Yet, understanding the differences between theory and practice is crucial for optics education, or more broadly STEM education. Past attempts to solve this problem, which has been exacerbated during the pandemic, included using simulations, remote laboratories, or distribution of lab kits to students [1]. These attempts, however, hinge on their accurate representation of reality, scalability, and cost, respectively. Instead, we propose using our platform called *iLabs*, which is available at www.ilabs.education. We based this platform on the iLabs website developed at Stanford in the 90s with the Optical Society's help through the "Optics for Kids" program. The old iLabs showed promising results for education [2].

The approach for the new solution is to first digitize an experiment in its entirety and then display it interactively on the aforementioned website [3]. For the first step, an automated software iterates through all states of an experiment. In the majority of cases, experiments are computer-controlled and a composition of a finite number of states. We provide software snippets illustrating how to write such iterative software. Then, the resulting data set can be uploaded using an interface on our website. For the second step, we created an interactive display of the data on the website. This display is focused on the visual element, using photographs taken during the recording in each respective state. It also recreates all controls and data displays of the original experiment. An impression of the display is shown in figure 1. Using the website, a student can change the input controls of the experiment, and the website shows a picture of the equipment in the respective new state and all data measurements. This measurement can include probabilistic features such as noise and uncertainty about the outcome [4], which is akin to actual physical experiments. The interactive experience is a core feature of iLabs. We aim to create a *Digital Twin* of the actual laboratory experiment that exhibits the same immersiveness for students. Such a Digital Twin can be used for the education of students and to display scientific results [5].

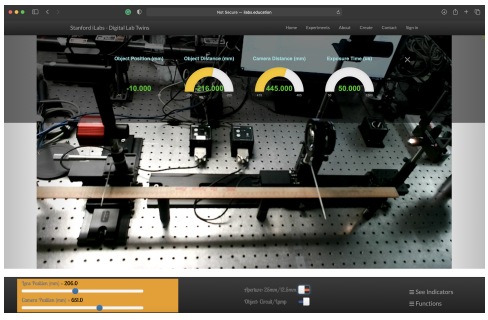

Fig. 1. Experimental Display using the iLabs interface

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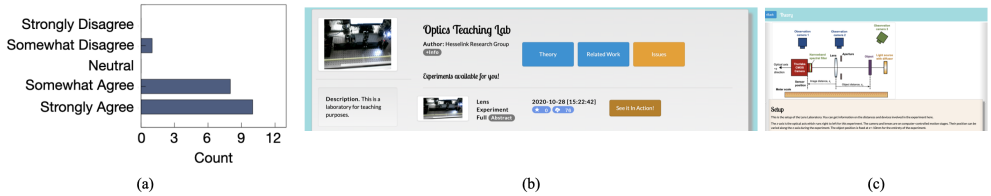
2. Case Study

To test out the potential impact of iLabs on education and learning, we have used it in one of Stanford's most foundational optics courses, called EE236A - Modern Optics, which had 22 registered students [6]. We could not include the course's usual laboratory and class demo components as we taught the course during the pandemic. Instead, we replaced them with a single lens imaging iLabs experiment in one of the homework sets. In this experiment, students could vary the distance between lens and object and lens and camera. They could then study the differences in the resulting image. The laws of geometrical optics, which the students encounter during the course, dictate these changes. We surveyed the students after they conducted the experiment and got positive feedback, primarily pointing towards the low barrier of access and the potential upside of using iLabs as an augmentation or training tool in addition to conventional labs (compare Figure 2 (a)).



(a) (b) (c)

Fig. 2. (a) Example of a survey response (reproduced from [6]). The question was: 'Please rate the following statement: iLabs can be a complementary learning tool to class lectures and homework exercises'; (b) Website navigation menu for an experiment, guiding to the experiment itself, theory, related works or, issues related to the experiment; (c) Example of a theory slide

3. Scalable Conversations

We recently added additional features to the platform to leverage and link to other online resources: theory slides, a related work section, and an issues platform (compare Figure 2). With theory slides, the author of an iLabs experiment can provide background information in a presentation-style fashion, allowing students to read up on the theory underpinning the experiment. The related work section enables authors to add references to the experiment, such as textbooks or research papers. Students can refer to this section for further educational support. The last addition, an issues platform, facilitates a conversation between students (peer-learning) or instructors and students. As an example, suppose there is a question about the experiment and the observations. In that case, students can post them there, look at a similar previously asked question and assist in answering questions they are capable of answering. Through this process, we can facilitate a scalable conversation around experiments.

4. Conclusion

In summary, the iLabs platform is a method to augment experimental learning with fully scalable interactive online experiments that function as an impetus for conversations. Experiments are especially suited to encourage discussions due to the unexpected nature of their outcome. We intend to create a larger iLabs community that we wish to encourage people to join.

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