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Interactive online lectures for asynchronous delivery

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Abstract. Physics teachers often use active learning techniques such as “clicker questions” in their lectures. We created a set of asynchronous online lectures that include clicker questions. Five instructors created and shared their Interactive Online Lectures for the first semester of an introductory calculus-based course. Each lecture consists of short video lecture segments interspersed with required multiple-choice clicker questions designed to help students understand the content. After submitting an answer, the student sees an explanation of why that answer is right or wrong. Instructors at five institutions used the lectures during the Fall Semester of 2020.

1. Introduction

Many physics instructors use videos in their instructional design to support active learning. For example, in Just-in-Time-Teaching [1] or flipped classroom approaches [2-3] instructors may assign lecture videos as homework so in-class time can be devoted to active learning, including problem solving, experimentation, discussions, etc. In fully online courses, video lectures can substitute for live online lectures. However, there is a growing number of instructors working to integrate more active-learning strategies into their teaching given substantial science education research which has shown that active learning is more effective than passive learning [4-5]. One way to make traditional lectures more active is to ask students “clicker questions” during the lecture, where students respond to multiple-choice questions using electronic polling devices. Using clicker questions supports learning because it provides both the instructor and students with immediate feedback as students are learning the material, and instructors can adjust their instruction based on this feedback [6-9]. For students, practicing what they are learning and receiving feedback helps them construct their own understanding [10-11] while keeping them mentally engaged [12].

This project builds on two recent projects of the research team, both involving the development of adaptive online materials. The first was the creation of Interactive Video Vignettes (IVVs) that target student conceptual understanding of topics for which they are known to struggle. IVVs are short (10 minutes or less), interactive, web-based activities that engage students in the learning process as they analyze real-world phenomena by making predictions and watching and learning from experiments. IVVs have been shown to be effective for student learning and have been developed for introductory physics [13-14], advanced physics labs [15], and introductory biology [20]. They are available on ComPADRE <https://www.compadre.org/ivv/> and through Cengage/WebAssign. The design of the IVVs addresses some of the barriers to adoption identified by Henderson and Dancy [17-18], including that they are likely to be easily recognized as useful by instructors because they attempt to address common alternate conceptions and student difficulties that instructors may be aware of, they support the active learning classroom as they can be assigned as pre-lectures or as homework, are easy to use and require no training.

Additionally, the research team has been creating Interactive Video-Enhanced Tutorials (IVETs), which focus on developing students' problem-solving abilities. IVETs are web-based activities that lead students through a solution using expert-like problem-solving approaches, such as those needed for solving problems involving conservation of energy or linear momentum. Preliminary results have shown the IVETs to be effective with medium to large effect sizes for the six IVETs for which student performance on a transfer problem was compared between students who completed the IVET with students who watched a video solution only [19].

IVVs and IVETs are examples of instructional materials that have been shown to effectively engage students outside of class. Their design allows them to be flexibly used in both online and in-person active learning classes. IVETs emulate an experience a student may have when working out a problem with peers or with TAs in a tutoring style discussion. Given our prior research experience, and given the abrupt move to online learning as a result of the pandemic, the next logical step for our work is to create interactive lectures aimed at emulating the experience a student would have in an active-learning classroom by interspersing short lecture segments with multiple-choice questions to which students respond and receive immediate feedback.

The aim of this project is to provide online, asynchronous video lectures that include clicker questions with appropriate built-in feedback. We developed a set of these Interactive Online Lectures (IOLs) for immediate faculty use in the first semester of introductory physics. A student "attending" an IOL will watch a short video, then answer a related multiple-choice question to check for understanding. Feedback will be provided if an incorrect answer is selected, and the student will be returned to the question to answer it again until he/she answers it correctly, at which point the reasoning for the correct answer is reinforced with additional feedback. The student will then move on to the next lecture/question segment. This design is based on prior research in human learning, which stresses the importance of feedback and guidance [20-21] to help students construct their own knowledge [10-11]. It makes use of the research literature on student difficulties and alternate conceptions [22] to create the clicker questions and the associated feedback, and incorporates multimedia learning principles [23] and research in online learning [24-28].

2. Pedagogical background

Personal response systems, often called clickers, have been used to promote active learning in the classroom [6-9, 28]. The use of clicker questions has been shown to support learning because they help students mentally engage with the material while informing the instructor when students need additional guidance [6-9, 29]. The frequent use of formative assessments, such as clicker questions, supports constructivism [10-11] through the process of providing feedback as students apply the concepts they are learning to various situations and construct their own understanding. Additionally, frequent questioning keeps students engaged and promotes individual accountability for learning [12], which is linked to improved learning.

Research on the use of clickers has suggested several best practices in which questions should:

- address common student difficulties or alternate conceptions, when possible [6, 30].
- focus on a single concept [6, 30].
- encourage sense-making [31].
- be designed in sets where questions are scaffolded to lead students to deeper understanding [8].

Beatty et al. [7] further suggest designing clicker questions to include goals that go beyond the learning of content and address process and metacognitive goals. Process goals refer to cognitive skills that the instructor promotes, which are typically associated with skills like problem solving, and metacognitive goals refer to helping students learn the purpose of physics and, for example, using it to reason about the world. IOL clicker questions should incorporate these best practices as much as practically possible. Additionally, they should be based on research in online learning, physics education research, and cognitive science. For example, research stresses the importance of providing opportunities for students to practice and receive immediate feedback [20, 21, 32] so clicker questions should be designed for this purpose. There is also a lot of research on the benefits of using online learning modules for pre-class activities [26, 33, 34].

3. Development and use of the Interactive Online Lectures

During the COVID-19 pandemic of 2020, many teachers (including some of the project team) had to quickly switch from classroom instruction to online or blended formats. Since the same technology we had been using for IVVs and IVETs can also be used to make IOLs, we decided to create a set of interactive lectures that would replicate active-learning classroom experiences in an asynchronous online environment for use in introductory physics courses in the Fall 2020 semester. To reduce the workload, we recruited faculty at other institutions to help make the videos and write appropriate clicker questions for them. We assembled the pieces into IOLs, which are hosted on the IVET server at RIT. In total, five instructors made 28 IOLs containing 64 clicker questions. One Interactive Lecture Demonstration [35] was also made. IOLs have now been used by over 250 students of seven instructors at five institutions.

The seven instructors used different strategies for implementing the IOLs and reported different outcomes for usage. One instructor used the IOLs as pre-class lectures for most topics in his calculus-based introductory physics course. He gave graded assignments that were closely related to the IOLs to encourage students to engage with them. Students completed one or more IOLs asynchronously for the first class period when a new topic was covered. Subsequent class periods covering that topic (usually two) were synchronous and online. Typically, over 90% of the enrolled students completed the asynchronous assignments related to the IOLs. In another case, three instructors at a large private university implemented a few IOLs instead of their usual YouTube video lectures, and required students to turn in written lecture notes to be checked by a TA. Most of their students completed the IOLs. In the remaining instances, the instructors recommended the IOLs as supplementary materials, and few students in their courses used them. This is consistent with previous research which found that some form of course credit is necessary for students to participate in online activities [36].

Figure 1 shows student survey results from Spring 2020 for three faculty who regularly teach introductory physics courses at the University of Cincinnati. The introductory physics course setting at

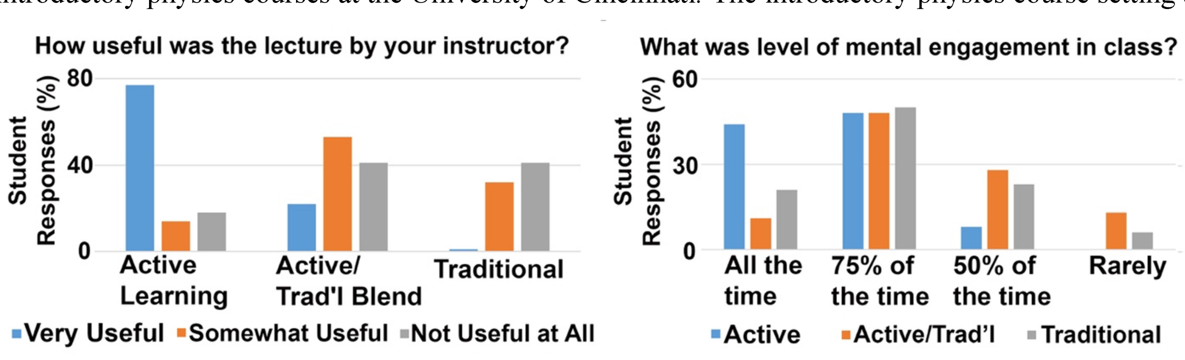

Figure 1. Results of two survey questions provided to students of three instructors of various teaching styles during Spring semester 2020 at the University of Cincinnati.

the University of Cincinnati is ideal for future testing of the IOLs in that there are significant numbers of women and underrepresented racial and ethnic minorities for our data collection. UC also has high rates of first-generation college students, including 21% on main campus and 45% at the branch campus. These include an instructor who uses active learning extensively in her teaching, an instructor who assigns pre-lecture material outside of class and combines lecture with students completing group worksheets in class, and an instructor who conducts a traditional lecture course. Note that all sections have approximately 135 students and 97%-100% of students across these sections claim to attend class 75% or more of the time, likely due to instructors counting attendance as part of the course grade. It is clear from Figure 1, however, that students are experiencing very different instruction, even though the sections use the same syllabus, pace of delivery, assigned homework, and exams. As one might expect, exam performance differs as well between sections. The active learning class regularly outperforms the other sections by as much as 15%. One aim of this project is to improve the delivery of content across all sections by using IOLs.

4. Typical IOL sequence

The sequence of a typical IOL is shown in Figure 2. A student "attending" this interactive lecture will login and watch the first video lecture segment. Next, the student will receive a multiple-choice clicker

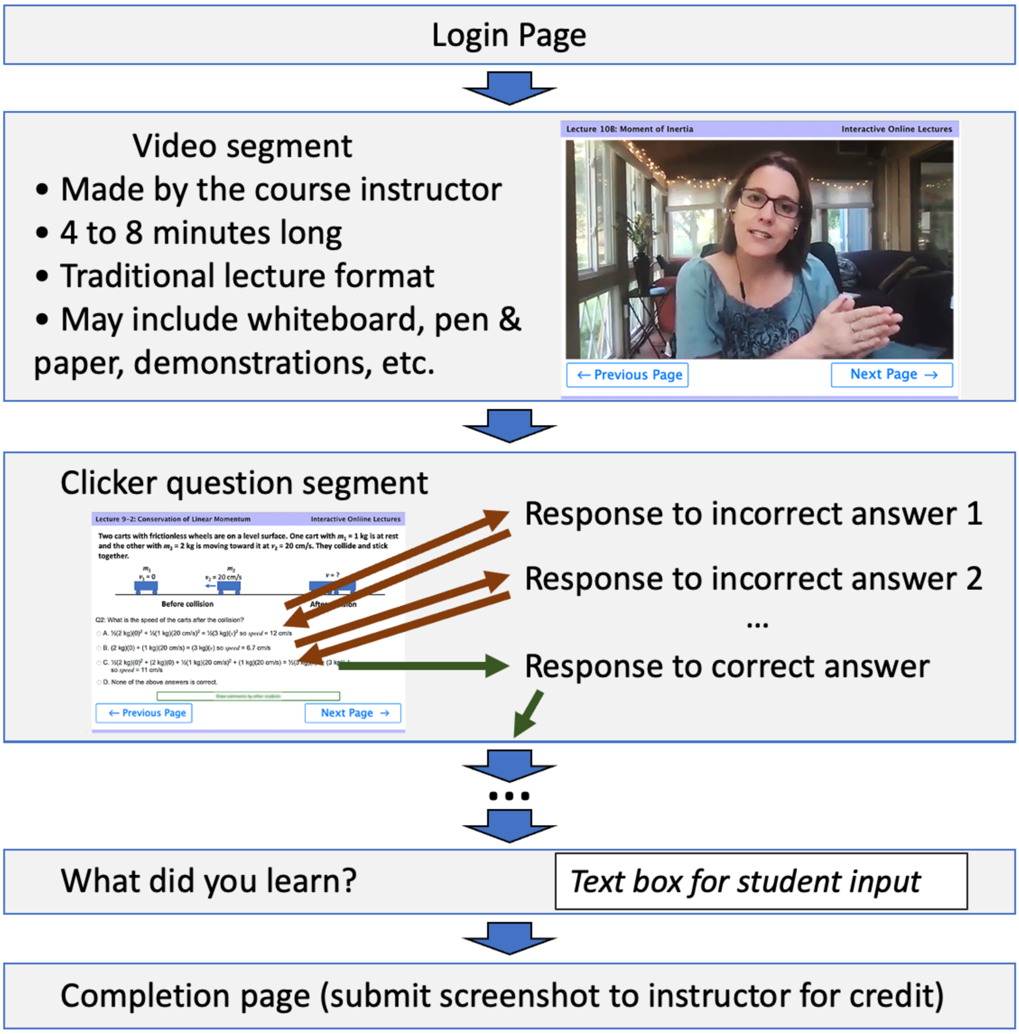

Figure 2. The body of an Interactive Online Lecture is a series of video segments, each followed by multiple-choice clicker questions designed to help the student understand the video segment.

question. After making a choice the student will be provided with feedback, which may be either a video or text with images. The feedback will indicate whether the choice was correct or incorrect. If it was incorrect, it will also provide a hint or partial answer to the question and direct the student back to the question for a second attempt. If the choice was correct, the feedback will explain why the choice was correct and then direct the student to the next clicker question or the next lecture segment. This sequence is repeated several times across the IOL. The student can navigate back to see the lecture segments again at any point, but forward navigation only takes place when the clicker questions are correctly answered. When the last segment is finished, the student is asked to summarize what was learned in a provided text box. This step is included in the design as it has been shown that the process of summarizing can support learning by reinforcing or transforming conceptual links in the student's mind [37-38]. The final page of the IOL is a completion certificate that may be copied or printed and turned in to verify completion, if required by the instructor. The page shows the student's login name, date, and the student's response to the "what was learned" question. The process identified here is similar across IOLs and incorporates best practices for multimedia learning as well as techniques developed through physics education research.

5. Sample clicker question

In *Lecture 11C: Angular Momentum Problem Solving*, following a 3.5 minute video lecture segment on how to recognize rotational kinematics problems, the students are given the clicker question shown in Table 1. As shown, each answer choice results in relevant feedback, and students who choose incorrect responses are sent back to the question to try again. In all of the Fall 2020 classes that used this IOL, 103 students eventually chose the correct answer D although some initially chose one or more incorrect answers: 11 had chosen A, 32 had chosen B and 23 had chosen C. This suggests that a quarter or more

Table 1. Example of a clicker question with answer choices and relevant feedback to the student.

Consider this problem: A centrifuge used in DNA extraction spins at a maximum rate of 7000 rpm, producing a "g-force" on the sample that is 6000 times the force of gravity. If the centrifuge takes 10 seconds to come to rest from the maximum spin rate: (a) What is the angular acceleration of the centrifuge? (b) What is the angular displacement of the centrifuge during this time?

Clicker Question: Could we solve this problem using kinematics?

Answer choice	Response to this answer choice
A. No, because it involves g-forces.	Incorrect. The g-force is not a force that causes rotation in this problem. It is a centripetal force that we use to find the angular acceleration of the centrifuge.
B. No, because we need Newton's Second Law for rotational motion to find the angular acceleration.	Incorrect. We do not know the torque that causes the centrifuge to slow down. The g-force is not a force that causes rotation in this problem. It is a centripetal force that we use to find the angular acceleration of the centrifuge.
C. No, because we need the moment of inertia of the centrifuge to solve it.	Incorrect. We will not need the moment of inertia, either in Newton's Second Law for rotational motion or in Conservation of Angular Momentum.
D. Yes.	Correct. We can solve this problem using the kinematic equations. One clue is that we are told how much time is required for the centrifuge to come to rest.

of the students had not understood the material in the lecture segment. We expect to write scripts to mine the database so we can study such results in more detail. For example, is there a pattern before students end on the correct answer? How much time did the students spend between choices? How often did students revisit the lecture segment after an incorrect answer?

6. Making an IOL

6.1. The script

The script should describe everything that goes into the activity: The words and actions for the narrator, any images that will be included, the questions for students, the answer choices, and the names of the response pages for all of the answer choices. The script will not only be used while making the videos, but also while setting up the question pages and the response pages.

The IOL should be designed around multimedia learning principles that are based on research of human cognition related to how external information is processed [39-40]. For example, rather than being solely text-based, many of the questions and responses should be visual, and cues should be used to narrow focus on relevant information and reduce extraneous cognitive load [39-40]. These features are based, in part, on the **modality** and **redundancy** principles [23] which suggest that information should be presented using complementary modalities, e.g., visual and auditory. According to these principles, students learn better with animation and audio narration than with animation and text [23]. This is particularly important when the context is complex, which is the nature of the lectures [41]. Similarly, research suggests that **visual information** is easier and more efficient to process than the same information in text [42]. Multiple representations of the concepts should be used in the responses as much as possible, since research in physics education has shown improved learning when students are taught to manipulate the same concept using a variety of representations (mathematically, graphically, diagrammatically, pictorially, etc.) [43-45]. Likewise, the principle of **signaling** should inform the design of IOLs. This principle is based on research related to cognitive load during problem solving [40] as well as empirical studies on the effects of providing visual signals (cues) to help learners process relevant information [46]. Before students move forward with a solution, they need to process the relevant problem information in their limited working memory [40, 47]. Students, therefore, often benefit from being guided (signaled) to recognize what information needs to be considered. Without this support, students may process irrelevant information and experience cognitive overload, thereby hindering learning [48]. Sweller [49] and Paas [50] consider the reduction of extraneous cognitive load as one of the main goals of instruction to help free cognitive resources for germane cognitive load (related to integrating what is learned from working on the task at hand with prior knowledge) and intrinsic cognitive load (related to the difficulty of the task and expertise of the student). The **coherence** principle suggests that any information in an instructional task that is not directly relevant be removed. The **segmenting principle** suggests that students learn more when they are able to control when to proceed within a multimedia learning module, which is already part of the IOL design. This ensures that students with different academic preparation are able to spend the time they need in order to learn from the lectures, thus staying within their zone of proximal development [51].

6.2. The videos

Each video should be short. Six minutes or less is a good goal for lecture segments, and anything longer than eight minutes should be either trimmed or separated into two parts with a question in between them. The answer choices to every question should lead to response pages, and any videos in the questions or responses should also be short. There are many tutorials and guidebooks about making educational videos. A good one made for the *2018 NSF STEM for All Video Showcase* is available at <https://stemforall2018.videohall.com/pages//about/moviemaking-guide>.

6.3. The web pages
A simple IOL can be implemented by creating a set of linked web pages, with one lecture segment video, one question or one response on each page. The navigation from page to page is done with ordinary HTML links or form elements. Videos can either be called directly or embedded from sites like Vimeo or YouTube. Additional features like logins or multiple-select questions will require a scripting language such as JavaScript or PHP. Experienced web designers or advanced web-design students will know how to do this.

7. Conclusions
A set of 28 Interactive Online Lectures has been created and used by over 250 students at five colleges and universities. Five instructors contributed scripts and videos. The lectures were made for emergency use during the covid-19 pandemic, but they will remain available for use in online and flipped classes. Figure 1 shows that students experience vastly different instruction in their lecture courses, so the use of IOLs should help reduce those differences. Since this is not a research project, no attempt has been made to assess the effectiveness of the lectures. The project website <https://ivet.rit.edu/IOL/> has guest-access links to all of the lectures.

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