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Interactive Multimedia in Teaching Physics Concepts Effectively

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Abstract. Multimedia communication refers to more than one medium of communication. For example, if we consider a textbook, it has some text at a minimum. It may also have pictures, graphs, tables of data, and so on. In the modern era of digital technology, its span has widened to audio and video recordings and interactive animations. This paper investigates the effectiveness of interactive multimedia tools in improving student learning of physics concepts in introductory college courses. We implemented interactive multimedia tools in the studio-style and Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP) classroom settings, and studied their impact on student learning of physics concepts through surveys on their perceptions related to the learning activities based on those tools. Our analysis of the survey data shows that the majority of the students who participated in the surveys found the interactive multimedia activities helpful for learning physics concepts.

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INTRODUCTION: MULTIMEDIA LEARNING

Traditionally, an educator used to be considered as a 'sage on the stage' but the research-based pedagogy advocates the role of an educator differently that an educator should be a 'guide on the side' [1]. This means that the learners should be at the focal point in a teaching-learning process and the educator, unlike lecturing, should play a role of the facilitator of learning. As the learner-centered pedagogy demands an active engagement of the learners in the learning process, the pedagogical activities should be designed accordingly. When a learner performs some relevant activities for learning, that is broadly categorized as an active learning; otherwise, the learning process would be passive like just listening to lecture, watching a video, or reading without engaging in relevant activities. In active learning, the activities can be some kind of hands-on activities, problem solving, working on group projects or collaborative discussions on a certain topic [2]. Research has shown that active learning increases student performance in science, engineering, and mathematics [3].

One way of involving students in active learning is by the use of properly designed multimedia tools. Because of a rapid development of technology, there are several types of multimedia tools which are readily available for use in our classrooms [4–9]. These tools can be used to convert the teacher-centered pedagogy to learner-centered one in which the students will take ownership of their learning [10–13]. It has been shown that proper implementation of carefully designed multimedia tools in instruction improves teaching by motivating students toward learning, and enhancing student learning of the material [14–24].

Here we will briefly introduce multimedia learning and the multimedia designing principles before we discuss their implementation and impacts on student learning.

Multimedia learning refers to the involvement of more than one media in teaching-learning activities, e.g., words, still pictures, videos, simulations, and animations [25].

There are primarily two channels by which external information flows to our sensory system [26]:

(i) **Auditory channel:** reading words/sentences or listening to them activates the *auditory channel*, and

(ii) **Visual Channel:** seeing pictures (including videos and animations) activates the *visual channel*.

For example, if we are planning to teach Newton's third law of motion, we can simply state it in words as 'To every action, there is an equal but opposite reaction' and explain it with an example as follows: when a swimmer pushes the wall of the swimming pull backwards, the wall

FIGURE 1. A demonstration of Newton's third law of motion in the International Space Station [27].

of the pool pushes the swimmer in the forward direction. These pair of forces: the 'force of the swimmer on the wall' and the 'force of the wall on the swimmer' form an 'action' and 'reaction' pair. The pair of forces are exactly equal in magnitude and act in opposite directions, i.e., forward and backward directions in this example.

The same law can also be taught by recording an audio statement or video recording and letting the students listen to the audio or watch the video. For example, Fig. 1 illustrates Newton's third law of motion demonstrated in International Space Station [27], in which two astronauts are pushing against each other. The picture clearly shows the action and reaction pair of forces applied by the astronauts on each other. This picture activates the visual channel for the information flow and the video [27] activates both the audio and the video channels, which help the students learn the material better.

In this paper, we are discussing our implementation of interactive multimedia [28] in teaching physics concepts in Newtonian mechanics, and electricity and magnetism of introductory level college courses and their effectiveness in learning physics concepts.

WHY MULTIMEDIA IN TEACHING AND LEARNING?

According to Richard Mayer, 'Multimedia instruction helps students learn more deeply because it takes advantage of the two separate channels: auditory and visual, and allows the students to go through the process of making multiple models to really understand the material that is presented to them' [29]. This means that the information from words via auditory channel and the information from pictures (still, videos, and animations) via visual channel make multiple models in our sensory system. These will make the transfer of knowledge more effective, deepening the learning of the material.

MAYER'S MULTIMEDIA DESIGN PRINCIPLES

A properly designed multimedia tool contains only the essential components for learning and do not burden the cognitive process with unnecessary information. Richard Mayer has given a dozen of multimedia design principles for effective learning [30]. Some of those principles, which guide on reducing or eliminating *extraneous* loads in learning, are as follows:

(i) **Coherence principle**: People learn better when extraneous words, pictures and sounds are excluded rather than included.

(ii) **Redundancy principle**: People learn better from graphics and narration than from graphics, narration and on-screen text. According to this principle, the additional 'on-screen text' creates an extraneous load in the cognitive process.

(iii) **Signaling principle**: People learn better when cues that highlight the organization of the essential material are added.

(iv) **Spatial contiguity principle**: People learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen.

(v) **Temporal contiguity principle**: People learn better when corresponding words and pictures are presented simultaneously rather than successively.

METHOD: IMPLEMENTATION OF INTERACTIVE MULTIMEDIA

We implemented interactive multimedia tools in our introductory physics courses, physics pedagogy classes, and astrophysics courses at Worcester Polytechnic Institute (WPI). In this paper, we will focus on their applications in the introductory physics courses with two different classroom settings: Studio-style instructional environment [31, 32] and the Student-Centered Active Learning Environment for Undergraduate Programs (SCALE-UP) [33, 34] classroom settings.

I. Multimedia Activities in a Studio-style Instructional Environment

We hear from many first-year college students that 'physics is hard' or 'physics is not my subject'. This can be because of the lack of their proper preparation in physics in their high school classes or because of some other factors [35]. Moreover, when they enter a lecture-based college classroom, they might lose their interest when they lag behind from some well-prepared students. As a result, it further creates frustrations in physics learning.

As we observed similar issues in introductory physics lecture-based classrooms at WPI, we piloted studio-style instructions [31] in introductory electromagnetism course, with 17 students in Spring 2018. The class structure per week was as follows: two studio-style classes of 1 hour and 50 minutes each and one class of 50 minutes. We split each studio class period as follows: a short motivational video or demonstration in the beginning ($\sim$ 5 minutes), a mini-lecture ($\sim$ 15 minutes), hands-on activities ($\sim$ 40 minutes) developed from eScienceLabs kit [36], collaborative problem solving ($\sim$ 40 minutes), and *think-pair-share* activities ($\sim$ 10 minutes) toward the end of the class. The plan for the 50 minute long classes was as follows: short interactive demonstrations and collaborative problem solving or exams.

Students' reflections on studio-style instructions were very encouraging. But we had some challenges and limitations to implement these instructions to large-sized studio classes. We, therefore, decided to implement technology-based interactive activities in those classes with 64 to 90 students, keeping the class structure similar to that of the pilot course. We selected *Physlet Physics* animations [4, 14] relevant to the physics concepts to be delivered, and developed worksheets [37] based on those animations. Students played with the animations in their laptop computers or smart phones, observed the physical phenomena shown in the animations, and discussed them with their peers at their table. Then they answered the questions in the worksheets, and submitted for grading. If any student was confused or lost, pedagogically-trained graduate Teaching Assistants (TAs) or undergraduate Peer-Learning Assistants (PLAs) or the course instructor guided them to reach the answers to the questions in the worksheets.

Fig. 2 shows an interactive animation activity on Coulomb's law implemented in introductory electricity and magnetism course. In this animation, students study Coulomb's interaction between charged particles by introducing point charges at specific points in the animation window, as described in the text box in each figure. They apply the laws of electric charges and the Coulomb's force equation to explain their observations in these animations, and answer the questions in the worksheet. The details of the activity can be found in the Worksheet-1, posted in *Open Source Physics* website [37].

We deployed an anonymous survey after the completion of the course to find student perceptions on multimedia learning activities. The survey question was,'How helpful were the worksheets based on the physlet simulations in understanding the physics concepts in this course? Please provide your comment.' We collected 185 responses for introductory electricity and magnetism course. Those responses were from multiple terms, a *term* at WPI being a *seven-week period of course delivery*. We analyzed the survey responses based on their perceptions on multimedia learning activities. The analysis has been presented in 'Results' section.

II. Multimedia Activities in a SCALE-UP Instructional Environment

Recently, we remodeled introductory Newtonian mechanics classes and started teaching them in a SCALE-UP en-

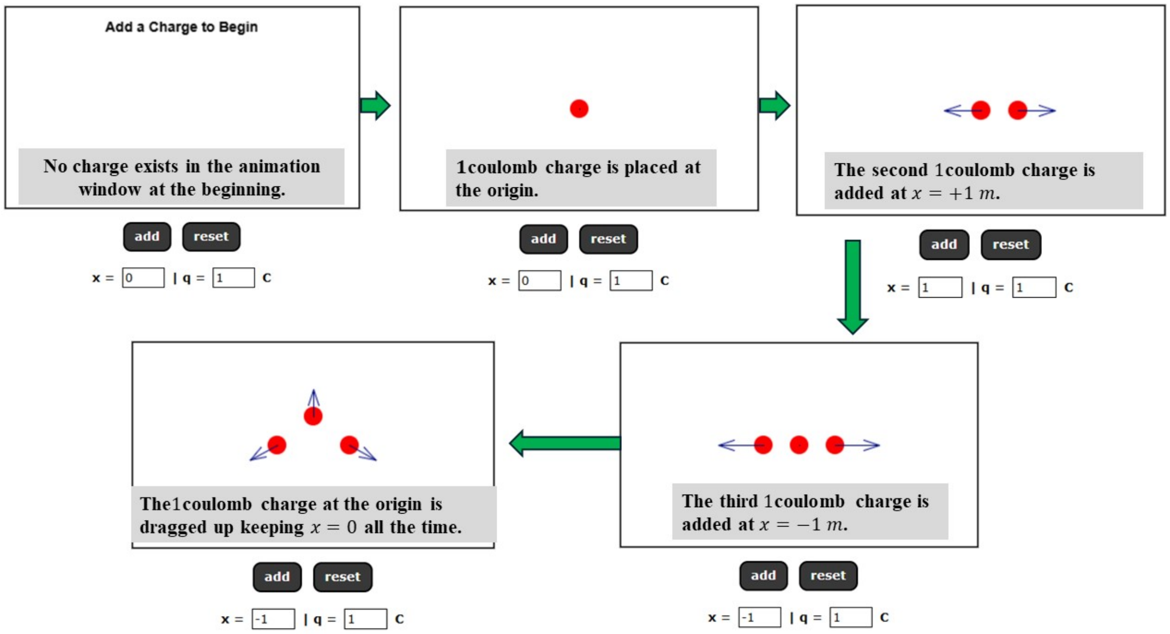

FIGURE 2. Snippets of Physlet animations for studying Coulomb's interaction between point charges [4].

vironment [33, 34], which could have up to 144 students. We implemented some selected *Physlet Physics* animations in these classes. Students played with the animations in their laptops or smart phones, discussed the questions in the worksheets with their peers, answered them, and submitted for grading. The worksheets developed and implemented in this course can be found in the *Open Source Physics* website [38].

Unlike studio-style instructions, we did these activities in 50-minute long classes twice a week. These classes were facilitated by 3 pedagogically-trained PLAs and the primary course instructor.

Fig. 3 shows a Physlet animation activity on Newton's laws of motion implemented in introductory mechanics course. In this animation, students study the motions of a ball projected by the ball popper mounted on (*i*) a cart at rest (Fig. 3, left), (*ii*) a cart moving to the right at a constant velocity (Fig. 3, middle), and (*iii*) a cart moving to the left at a constant velocity (Fig. 3, right). They discuss the questions in the worksheet with their peers at their table, answer them, and submit the worksheet for grading. The details of the activity can be found in the Worksheet-4, posted in *Open Source Physics* website [38].

The worksheets played a dual role in these classes: they were implemented as learning tools by which students learned the key concepts related to the topics of interest. These worksheets also served as formative evaluation tools [39]. They were graded by the TAs/PLAs with their relevant feedback.

We deployed an anonymous student perceptions survey for this course, similar to that in electricity and magnetism course, collected 130 responses from multiple terms, and analyzed them. The analysis has been presented in 'Results' section.

RESULTS AND DISCUSSIONS

As mentioned in the 'Method' Section, we deployed an anonymous survey after the completion of the course with the following key question: 'How helpful were the worksheets based on the physlet simulations in understanding the physics concepts in electricity and magnetism course? Please provide your comment.'

There were a total of 185 survey responses from various terms. We analyzed the responses based on their perceptions of multimedia activities in learning physics concepts, by categorizing them into four groups: very (extremely) helpful, helpful, neutral, and not helpful. The results are shown in Fig. 4. Similarly, we collected 130 survey responses in the Newtonian mechanics course offered in various terms, and analyzed them by categorizing their perceptions into four groups. The results are shown in Fig. 5. In both figures [Fig. 4, 5], the number of respondents for student perception 'very helpful' also includes the number of respondents for the student perception 'extremely helpful'.

Some representative responses from students with perceptions 'extremely helpful/very helpful/helpful' were as

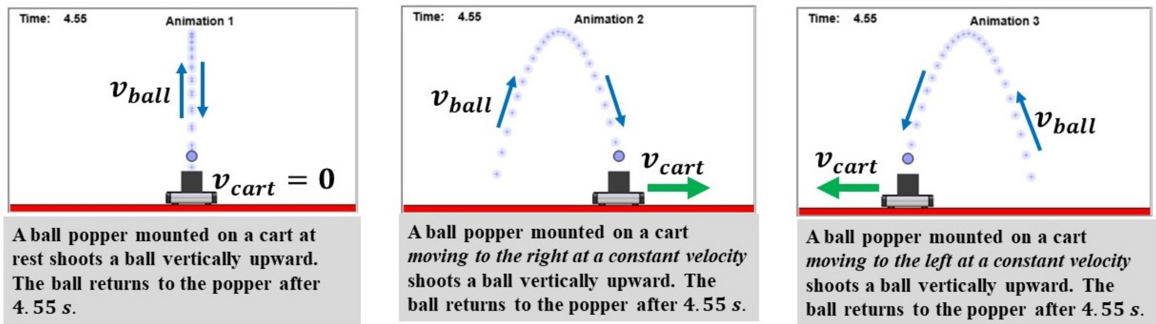

FIGURE 3. Snippets of Physlet animations for studying Newton's laws of motion [4].

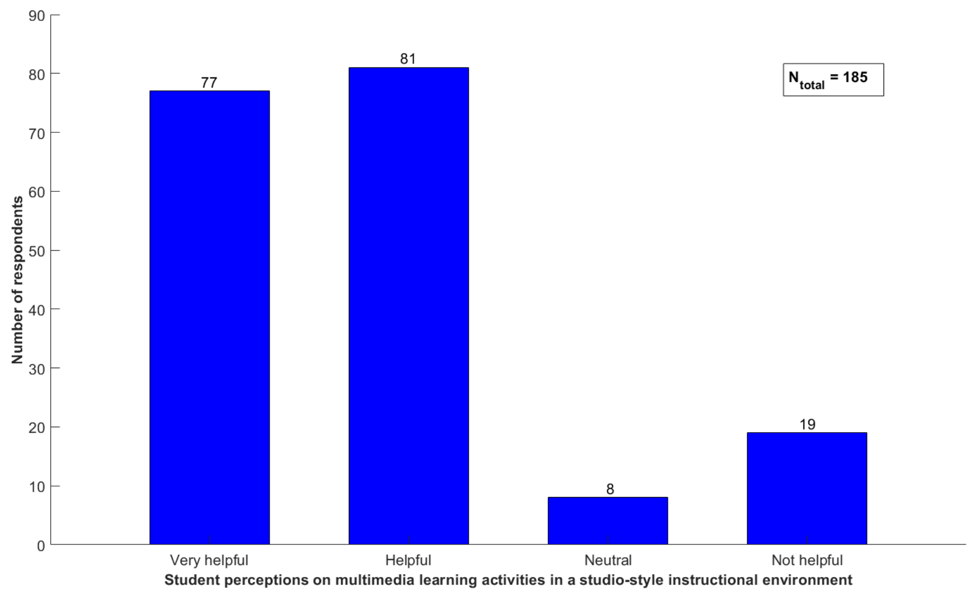

FIGURE 4. The student responses from introductory electricity and magnetism course taught in a studio-style environment.

follows:

(i) 'The worksheets were helpful in simplifying the key concepts we learned in class. They provided as a good resource to test my understanding of concepts after lectures. I also like how the worksheets broke up the lectures.'

(ii) 'They were helpful for visualization to see how the concept plays out. They also helped with the conceptual questions on homework and exams. Some of them were pretty challenging but that was not necessarily a bad thing because the professor and PLAs walk around to provide help.'

(iii) 'I thought the worksheets were very helpful in locking in what we learned during the lecture portion of the class. After we learned all the relationships and equations and ideas in the lecture, we could actually apply them in the simulation, which was very helpful in understanding the concepts.'

(iv) 'They (the worksheets) were very helpful. It's nice to see the actual concepts laid out as we're doing the problems, because that really assists with the understanding of everything that's going on.'

(v) 'They provided a visual representation of the current topic we were learning in physics, which helped to facilitate my understanding of the material.'

The interactive multimedia animations were found equally useful by the TAs and PLAs who facilitated student learning in the active learning classrooms [40].

About 10% of the participants in each course responded to the survey question that they found the multimedia activities 'not helpful'. Some representative responses from

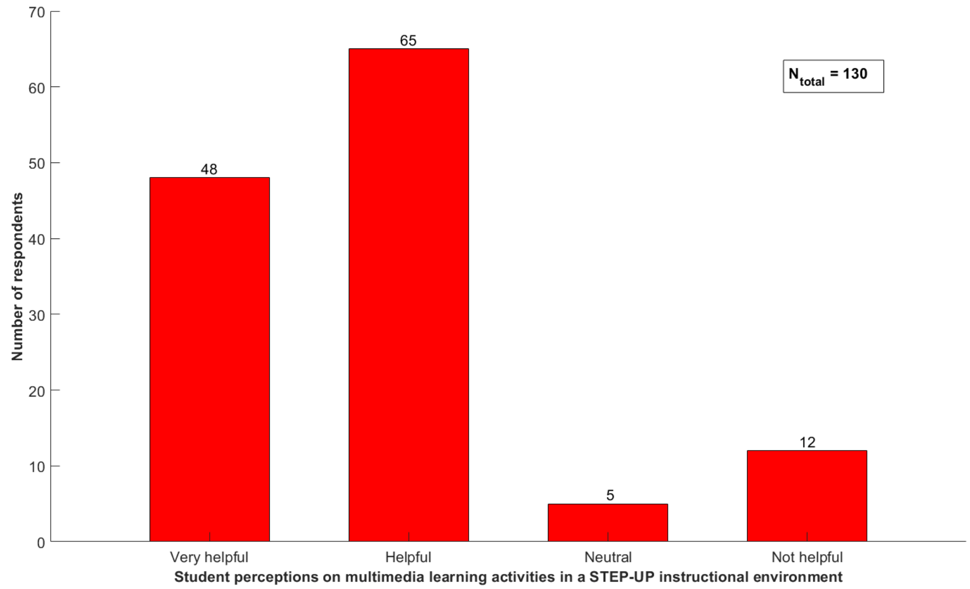

FIGURE 5. The student responses from introductory mechanics course taught in a SCALE-UP environment.

students with this perception were as follows:

(i) ‘The worksheets were not super helpful, but not sure what would make a better replacement. I think the worksheets could be good for someone who is behind on the material and needs to walk through work slower’.

(ii) ‘The worksheets were honestly, not helpful at all. I’d much rather have gone over more types of problems during the discussion sessions, instead of doing the worksheets.’

Some respondents (about 4%) remained ‘neutral’ in the survey who mentioned that they neither found the worksheets ‘helpful’ nor ‘not helpful’ in learning physics concepts. They wrote that they already knew the concepts delivered by the worksheets and took the worksheets as the grade boosters. Some others said that the worksheets were easy, and they just kept themselves engaged in group discussions at their table.

CONCLUSIONS AND DISCUSSIONS

The work presented in this paper is an outcome of the implementation of interactive multimedia tools (physlet animations) in teaching introductory physics classes in WPI active learning classrooms. These activities were supported by pedagogically trained TAs/PLAs. The results show that about 87% students in introductory mechanics course taught in SCALE-UP environment found these activities very helpful/helpful in learning physics concepts. Similarly, about 85% students in introductory electricity and magnetism course taught in studio-style environment found these activities very helpful/helpful in learning physics concepts. These activities helped them visualize abstract physics concepts, and the animation-based worksheets served as learning tools where they could apply the physics formulas and equations presented in the class.

A small fraction ($\sim 4\%$) of the participants found these activities neither helpful nor unhelpful. They just considered the worksheets based on these activities as grade boosters or means of keeping them engaged in discussions. The participants who had responded that the worksheets were ‘not helpful’ ($\sim 10\%$) explained that they were trivial to them and the time could have been better used for other activities like problem-solving or some other exercises.

In summary, properly designed and carefully implemented interactive multimedia tools make physics learning fun and they help students learn the physics concepts deeply.

FUTURE DIRECTIONS

In this research, we focused on the impact of interactive physics animations in learning physics concepts through perception analysis. It will be very relevant to study other impacts of interactive physics animations like developing problem-solving skills, analytical skills, and/or modeling of physical phenomena. We will be looking into these aspects in future. We have also been creating short interactive physics educational videos in collaboration with WPI undergraduate students as a part of their interactive qualifying projects [41–44]. These videos are made publicly available in YouTube [45–47], and their reports have been published by WPI Library in 'Digital WPI' [48–50]. We will be implementing these videos and investigating their impacts in learning physics concepts and building up their problem solving skills.

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