Adaptations of learning glass solutions in undergraduate STEM education

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One of the main issues STEM faculty face is promoting student success in large-enrollment classes while simultaneously meeting students' and administrators' demands for the flexibility and economy of online and hybrid classes. The Learning Glass is an innovative new instructional technology that holds considerable promise for engaging students and improving learning outcomes. In this report we share the results of an efficacy study between an online calculus-based physics course using Learning Glass technology and a large auditorium-style lecture hall taught via document projector. Both courses were taught with the same instructor using identical content, including exams and homework. Our quasi-experimental design involved identical pre- and post-course assessments evaluating students' attitudes and behavior towards science and their conceptual learning gains. Results are promising, with equivalent learning gains for all students, including minority and economically disadvantaged students.

Keywords: Learning Glass, Effective Online Classroom, Online Inquiry Oriented Courses

Introduction

Against the economic backdrop of workforce demands forecasted by the report of the President's Council of Advisors on Science and Technology (PCAST, 2012), universities in the US are striving to meet the needs of their students with fewer resources. One way universities are trying to address these needs with shrinking resources is to offer large enrollment courses using large lecture halls or online or partially online (also called "hybrid") formats.

In this paper, we report the results of an investigation integrating an innovative new technology, the "Learning Glass", and how it can be leveraged to meet these challenges. One of the authors developed the Learning Glass as a low-cost, open technology that facilitates communication in STEM courses by allowing a lecturer to look at his or her audience while writing on a transparent surface. The Learning Glass screen acts as a transparent whiteboard. The instructor writes on a glass screen with LED illuminated edges. A camera on the opposite side of the glass records the video and horizontally flips the image (and hence the instructor is not required to write backwards as seen in the Figure 1). The Learning Glass allows the instructor to use a full range of communication modes and visual cues to clarify ambiguous or subtle concepts, and engage students.

Figure 1. Learning Glass enable the instructor to face the students while writing on the board

Schmid et al. (2014) defined an effective online classroom as one that provides learning outcomes equivalent to the same course offered face-to face. In order to assess efficacy of the Learning Glass in the undergraduate classrooms, we conducted a quasi-experimental study in two undergraduate calculus-based physics courses with the following research questions:

Research Questions

1. How does student success in the Learning Glass courses compare with student success in standard courses? In particular, does the Learning Glass environment mitigate differential student success by demographic subgroups?
2. What instructor behaviors (e.g., gestures, modeling real time struggle and errors) take advantage of the affordances of the Learning Glass and contribute to student engagement? In particular, how do students perceive instructor presence in standard and Learning Glass classes?
3. Is it effective to integrate the Learning Glass into online classrooms?

Theoretical Background

The PCAST report (2012) calls for the wide-scale adoption of empirically validated teaching and learning practices as one way to increase retention of STEM majors, and the key practice the report highlights is "engaged learning." In this study we examine how the Learning Glass might help transform traditionally passive courses into more engaged courses by increasing instructor immediacy and facilitating communication. In the following paragraphs we describe each of these potential affordances of the Learning Glass in more detail.

Media Richness

Media richness theory is used to analyze communication and media choices with the goal of reducing ambiguity of communications (and increasing immediacy) by selecting the most appropriate media type (Newberry, 2001). The theory postulates that for ambiguous tasks, understanding improves when communicators use "richer" media. "Richness" is determined by the capacity of the medium to facilitate instant feedback, transmit verbal and nonverbal cues, enable the use of natural language, and convey a more personal focus (Daft & Lengel, 1984). Rich media are characterized as having the capacity to convey the most information, while lean media have a lesser capacity. The Learning Glass is very rich media having the capacity to provide all of the affordances associated with rich media when used in a synchronous manner.

Immediacy, and Student Learning

In online and hybrid settings, communication technologies vary in their capabilities to convey messages and verbal or visual "immediacy" cues. Immediacy has been defined as perceived psychological or physical closeness (Christophel, 1990), created in part by nonverbal physical cues such as smiling, a relaxed body posture, making eye contact, and verbal cues that include the use of humor and personal examples (Hostetter & Busch, 2006). In recent experimental studies conducted by Schutt, Allen, and Laumakis (2009) and Bodie and Bober-Michel (2014) confirmed that instructor behaviors that have been shown to reduce psychological distance in face-to-face settings also positively influenced learning outcomes in online settings. Interestingly, results of the Bodie and Bober-Michel (2014) study of cognitive learning showed that participants exposed to higher-immediacy instructor behaviors using rich media performed significantly better at post-test, immediately following the teaching session.

Student engagement & Peer Instruction

In a meta-analysis of existing literatures on online learning (Means, Toyama, Murphy, Bakia, & Jones, 2009) and on using technology in the classrooms (Schmid et al., 2014) researchers have concluded that "learning is best supported when the student is engaged in active, meaningful exercises via technological tools that provide cognitive support" (Schmid, et al., 2009, p. 285). A study by Zhang, Zhou, Briggs, and Nunamaker (2006) found that the effect of video on learning depended on the learner's ability to control the video ("interactive video").

There is a wealth of research in mathematics and science education research demonstrating the effects of peer instruction in large classroom settings (Crouch, & Mazur, 2001). Peer instruction is a pedagogical strategy in which the lecture is interspersed with short conceptual tests designed to reveal typical difficulties and misunderstandings and to actively engage students during the lecture. Students' interactive-engagement within the class has been shown to be correlated to students' learning gain (Prince, 2004; Redish, Saul, & Steinberg, 1998).

We conjecture that using the Learning Glass has significant potential for increasing the extent to which learners feel connected and form relationships with their instructor, even in large-lecture and online/hybrid classes. Such connectedness and feeling of instructor presence (immediacy) has been shown to be a key indicator of persistence, especially for women and underrepresented students (Good, Rattan, & Dweck, 2012; Seymour, 2006).

Research Design and Methods

We used a quasi-experimental design to investigate the adaptation of Learning Glass technology during the spring 2015 semester. This study included two classes of Introductory Calculus-Based Physics, both taught by one of the authors, using identical pre- and post-course assessments to evaluate students' attitudes and behavior towards science and their conceptual understanding of physics concepts. At the post assessment, we also included a survey to assess students' measure of instructor immediacy. When signing up for the course students did not know that the two sections would be different. We also used the pre-assessments to create a baseline for our quasi-experiment study. We then used the results of the post-assessment to compare students' conceptual understanding between the two classes, their attitude towards physics, and their view of instructor immediacy.

Population and Setting

The first class (LG section), which met at 8:00 AM, used Learning Glass in front of a live studio audience of rotating sets of 20 students that were enrolled in the course (shown in the Figure 1). As seen in Figure 2, the lecture streams to the remote students via MediaSite and incorporates peer instruction techniques such as clicker questions via online breakout rooms and virtual whiteboard of Blackboard Collaborate technology to engage students at home. There were 215 students in this class.

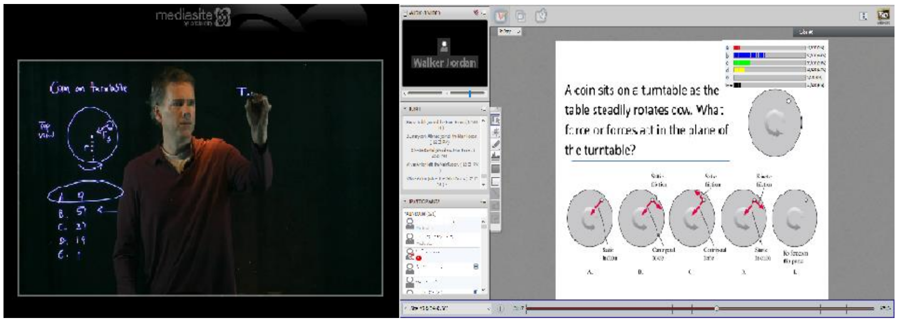

Figure 2. While instructor discussing students' difficulties with a clicker question, students can interact online and discuss the questions with their peers and their instructor.

The second class (standard face to face section) was delivered at 9:00 AM in a large auditorium-style lecture hall via document projector and used in-class clickers to engage the students. This class had 327 students. The content, homework, and exams were identical in both classes. Because of administrative difficulties, it was impossible to conduct a complete random-control study with these two classes, but as previously mentioned, students did not know that the sections would be different when registering for the course. During the first week of the semester there was very little movement of students to different sections, about 10% attrition from Learning Glass to face to face section.

In order to provide peer-instruction opportunities for the students in the Learning Glass section, we utilized an online conferencing system called "Blackboard Collaborate". Blackboard Collaborate is an online system that allows users to conduct and record synchronous virtual classes and meetings. Synchronous viewers at home were able to participate in "clicker" questions posed by the instructor, using the Blackboard Collaborate toolbox (essentially a high-tech virtual chat room with common whiteboard). These students were also able to watch the rich media lecture using MediaSite TM created by Sonic Foundry (left part of Figure 2). Belvins and Elton (2009) had shown that among three instructional hardware/software packages, MediaSite is the preferred format when video and audio of the instructor are shown simultaneously with the power point slides (clicker questions).

Data Collection

To answer the first research question, we needed to build a baseline for students' attitude and prior knowledge of physics concepts. Identical surveys were used as pre- and post- assessment so we could analyze how the Learning Glass intervention had impacted students' conceptual understanding of physics and their attitudes. Our pre- and post-course assessments included the Force Concept Inventory (FCI) (Hestenes, Wells & Swackhamer, 1992) and Colorado Learning Attitudes about Science Survey (CLASS) (Adams et al., 2006). In order to answer the second research question, in addition to the conceptual understanding and attitude surveys, we used a well-established instrument (Bodie & Bober-Michel, 2014) to measure the instructor immediacy at the end of the semester. Towards the end of the semester, we were also able to collect analytical data on the students' usage of Learning Glass videos from the MediaSite server where the class videos were streamed and recorded and recently we were able to obtain the demographic data for our students in both classes. These data included students' SAT scores, ACT scores, and their majors. Two indicators helped us distinguish minority and economically disadvantaged students: being part of the minority educational opportunity program and eligibility for financial aid.

Data Analysis

To answer the first research question, we used the students' responses to the pre- and post-assessment surveys from both sections. To answer the second research question, we compared students' responses to the immediacy survey. Based on the findings for first and second research questions, we addressed the third research question as well.

Students' responses to the force concept inventory were assessed based on a rubric provided by the designers of the FCI (Hestenes, Wells, & Swackhamer, 1992). Each student received a comprehensive score for their correct responses to the FCI survey (out of maximum 30). Students also received a comprehensive score for their responses to the attitude survey.

Most of the attitude survey's questions were quantified based on the psychometric Likert scale. So if a student had chosen C on the second question of attitude survey (question 37 on our survey), their answer would be quantified as 3. Students' responses on the immediacy survey were quantified similarly. Factor analysis of the CLASS survey had revealed several categories (Adams, et al., 2006) that we used in comparing the two sections: students' attitudes on personal interest, real world connection, problem solving confidence, sense making efforts, and conceptual understanding.

To compare the students' learning gains between the two classes, the learning gains were calculated using the following formula for each student:

$$Learning\ Gain = \frac{Post-Assessment\ FCI\ Score\ \ -\ \ Pre-Assessmnt\ FCI\ Score}{30\ \ -\ \ Pre-Assessmnt\ FCI\ Score}$$

Results

The data was first cleaned to remove incomplete surveys; out of 215 students in the Learning Glass class we registered 125 valid surveys, for the face-to-face classroom we registered 205 valid surveys. First we looked at the students' performance on pre and post surveys between the two sections. Then we compared the learning gains between the two sections and the learning outcomes of minority and economically disadvantaged students. We then analyzed the results of immediacy surveys and the effects of Learning Glass on student learning.

Students' Performance on the Pre- Attitude Survey

To compare students' comprehensive scores on the attitude survey, we conducted an independent sample t-test. Levene's test for equality of variances came out to be 0.183 which is larger than 0.10, so it confirmed the assumption that variances of students' scores on the pre-attitude survey for both sections were the same. The independent-samples t-test confirmed that there was no significant difference in comprehensive attitude score between the face-to-face class (section 2) (*M*=151.09, *SD* = 13.561) and the Learning Glass class (section 1) (*M*=148.63, *SD*=14.954). The magnitude of the differences in the means was small (eta squared = 0.007).

Students in both sections had similar scores on the CLASS survey categories except in the conceptual understanding domain. Comparing to the students in the Learning Glass section (*M* = 20.31, *SD* = 3.704), students in the standard face-to-face class (*M* = 21.39, *SD* = 3.361) had shown larger mean scores ($p < 0.01$) for the questions related to their understanding that physics is coherent and is about making sense, drawing connections, and reasoning not memorizing.

Students' Performance on the Pre-FCI Survey

The one-way ANOVA test indicated a significant difference between the students' performance on the FCI ($p < 0.01$). Students in the standard face to face section performed higher on the pre- FCI (*M* = 12.75, *SD* = 5.694) than the students in the Learning-Glass section (*M* = 11.40, *SD* = 5.585).

It appears that the difference in the mean value of students' performance on the pre-assessment FCI could be due to differences in the students' majors (standard section had more engineering majors) or it could be due to students' limited prior knowledge and skills necessary to advance in the undergraduate classroom. Analyzing the demographic data between the two sections illustrated that statistically there was a significant difference in student scores on SAT Math ($p < 0.05$) with standard section scoring higher, while there was no significant differences on their scores in SAT Verbal exams or ACT scores.

In order to see whether there was a significant difference in the student performance on pre FCI while controlling for their majors and their prior preparation (quantified by their SAT Math scores), we conducted one-way between-groups analysis of covariance. After adjusting for their majors and their prior preparation, there was no significant difference between the two section performances on Pre- FCI (F (1, 272) = 0.184, $p = 0.668$).

Students' Performance on Post Attitude Survey

An independent-samples t-test was conducted to compare the students' scores on the attitude survey for face-to-face class and the Learning Glass class. Similar to the pre-attitude results, there was no significant difference between the students' comprehensive scores on the post-attitude survey for face-to-face students (*M* = 143.57, *SD* = 14.872) and Learning Glass students (*M* = 140.62, *SD* = 18.40). The magnitude of the differences in the means was very small (eta squared = 0.007). The difference we had seen in the conceptual understanding category had been eliminated and both sections had similar mean scores on all the CLASS survey categories.

Students' Performance on the Post FCI

Similar to the pre-assessment, the face-to-face class outperformed the Learning Glass students. An independent-samples t-test was conducted to compare students' performance on the post FCI in face-to-face and Learning Glass classes. There was a significant difference (t (327) = -2.694, $p = 0.007$) in the face-to-face students' performance on post FCI (*M* = 17.54, *SD* = 5.933) versus the Learning Glass students (*M* = 15.72, *SD* = 6.006). The magnitude of the differences in the means was very small (eta squared = 0.009). In order to normalize these differences, students' learning gains were compared.

Learning Gains Comparison

The independent-samples t-test was conducted to compare the students' learning gains between the two classes. There was no significant difference in learning gains for students in the face-to-face class (*M* = 0.27, *SD* = 0.31) and students in the Learning Glass class (*M* = 0.24, *SD* = 0.26). Students' learning gains were the same between the two classes.

Learning gains of minority and socially economically disadvantaged students

A two-way between-group analysis of variance was conducted to explore the learning gains for minority and economically disadvantaged students for each section. The effect of being a minority (F (2, 323) = 0.006, $p = 0.994$), being in either section (F (1, 323) = 0.128, $p = 0.226$) and the interaction effect (F (2, 323) = 0.675, $p = 0.24$) did not reach statistical significance. So there was no significant difference in the students' learning gains between the two sections. One could claim that despite the differences in students' prior knowledge, this instructor had created equal learning opportunities for the students from diverse backgrounds.

Level of immediacy between the two sections

The students in the Learning Glass section found the instructor more immediate. The independent samples t-test, a parametric test of significance was used to determine a significant difference between the Learning Glass students' scores on the immediacy survey ($M = 80.13$, $SD = 11.790$) and the traditional face-to-face section ($M = 75.25$, $SD = 12.260$; $t\ (327) = 3.554$, $p = 0.0001$, eta squared = 0.04). The relation between level of immediacy students feel towards the teacher and learning gains in both sections was investigated using a Pearson product-moment correlation coefficient. There was a strong, positive correlation between the immediacy and learning gains in the Learning Glass section ($r = +0.25$, $n = 125$, $p < 0.01$) however there was no correlation between these two variables in the face to face classroom ($r = 0.126$, $n = 204$, $p = 0.073$).

Immediacy in the Learning Glass classroom

Students in the Learning Glass section felt their teacher being more immediate towards them. This could be due to the rich media provided by the MediaSite delivery method. We therefore looked at the correlation of MediaSite analytical data and level of immediacy. Level of immediacy was significantly correlated to the total number of times students watched the videos ($r = 0.306$, $n = 123$, $p < 0.01$) and the number of times they watched the lecture live ($r = 0.247$, $n = 123$, $p < 0.01$). There was no correlation between the immediacy and total number of hours students spent watching the lecture videos ($r = 0.168$, $n = 123$, $p = 0.064$). The last piece of analysis is investigating the relationship between the learning gains and level of immediacy and the MediaSite analytical data.

Effect of the Learning Glass on student learning

The data obtained from the MediaSite hosting the Learning Glass videos showed three variables: For each student, it showed the number of times they watched the lecture live, the total number of times they watched the videos including asynchronous views, and finally the total number of hours they spent on watching the videos. In order to look at the predictability of these factors, we employed hierarchical multiple linear regression. Hierarchical multiple regression is a regression technique used to generate and compare the predictive models for a continuous dependent variable (learning gains in the Learning Glass section) using different sets of independent variables (level of immediacy, total number of live views, total number of times students watched the video and total number of hours spent watching the videos). The hierarchical multiple regression revealed that level of immediacy ($p < 0.05$) and total number of times students watched the lecture live ($p < 0.05$) contributed significantly to the learning gains ($F(2,122) = 8.828$, $p < 0.001$).

Conclusion

Based on this preliminary analysis we can claim that integrating Learning Glass technology into the online classroom can provide an effective learning opportunity where students reach the same level of learning outcomes as the students in a standard face-to-face classroom.

An ideal efficacy study would have had randomly distributed populations to create a baseline. As we saw in the results of the analysis, our two populations had a similar attitude towards physics to start with but performed differently on the pre-conceptual assessment. We saw the same differences occurred at the end of the semester, but the students in the Learning Glass class and the standard face to face class had similar learning gains.

Students in the Learning Glass section had found the instructor more immediate than the face to face section. This feeling of connectedness is a key predictor of persistence in STEM fields so one can claim that Learning Glass technology has the potential to increase retention rates in undergraduate STEM majors. Learning Glass is an effective technological replacement to the large auditorium style classroom and has the capability of providing equal learning opportunities for students from all walks of life.

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