The Lecture Hall as an Arena of Inquiry: Using Cinematic Lectures and Inverted Classes (CLIC) to Flip an Introductory Biology Lecture Course

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ABSTRACT

Two sections of an undergraduate introductory biology lecture course were run in parallel as a pedagogical experiment. One section (32 students) was taught in a long-established, traditional manner, with lectures delivered during class, readings assigned in a textbook, and access to lecture graphics/slides provided via the online syllabus. The other, "flipped" section (16 students) lacked both required reading assignments and in-class lectures. Instead, students were assigned online cinematic lectures (cinelectures) for viewing outside of class. These cinelectures, delivered via YouTube, incorporate multimedia elements. In class, students were broken into small groups and engaged in active learning assignments. Accounting for all sources of content, the subject material covered was the same for both sections and assessments of learning were identical quizzes and examinations. Statistically significant differences in learning were observed during the first third of the semester, with the flipped-class students performing better on all tests and quizzes. These differences disappeared during the second two thirds of the semester, coincident with a large increase in the number of views of cinelectures recorded on the course YouTube channel. Survey of the traditional class revealed that approximately 3/4 of the students had learned of the cinelectures at this time and had added viewing of these to their study, providing an internal, if initially unintended, control sample to the experiment. These results, along with other, subsequent applications of the flipped model I term CLICing, provide evidence that supports the conversion of traditional biology lecture classes to an inverted format.

INTRODUCTION

This report describes an experiment in the implementation of a particular model for flipping an introductory biology lecture course at a small, comprehensive university. Because flipping is becoming increasingly popular, and because assessment of the effects of this type of reform at the post-secondary level are sorely needed, this study bears import for a wide range of biology educators.

The Need for Active Learning in Undergraduate STEM Education

“
A lecture is a process by which the notes of the professor become the notes of the student without passing through the minds of either.” – R.K. Rathbun (cited in Alberts, et al., 2007)

Limitations of traditional lectures as a primary pedagogical tool in teaching science have been widely recognized over the years, satirically in some cases. Unfortunately, this class format prevails as the most common approach to science, technology, engineering, and mathematics (STEM) education at the post-secondary level. STEM courses should afford students the opportunity to practice critical thinking and high-order cognition, help them integrate knowledge into conceptual frameworks, guide them in linking prior learning to new knowledge, and aid them in developing problem solving skills that allow the application of concepts to situations that are not explicitly memorized. However, these goals are rarely realized for the majority of students in the traditional lecture model. For most students, lecturing promotes memorization of facts rather than fostering deep understanding, and even high academic achievers sometimes gain little understanding of basic science concepts through traditional didactic lectures.

To remedy this situation, numerous clarion calls for reform of standard lecture delivery by incorporating active learning (AL) in the classroom have been forwarded by august science education advisory bodies and science education researchers. Indeed, there is a broad empirical fundament that supports the use of AL in science classrooms. Specific examples of the benefits of AL
in undergraduate biology education include: 1) the observation that substituting daily and weekly practice in problem-solving, data analysis, and other higher-order cognitive skills for lecture-intensive course design improved the performance of all students and reduced the achievement gap between disadvantaged and non-disadvantaged students; 2) the finding that an intense, inquiry-based, learner-centered experience was associated with long-term improvements in academic performance; 3) the measurement of significantly higher learning gains and better conceptual understanding when student participation and cooperative problem solving during class time was substituted for traditional lecturing; 4) evidence that teaching biology in an AL environment is more effective than traditional instruction in promoting academic achievement, increasing conceptual understanding, developing higher level thinking skills, and enhancing students’ interest in biology; 5) the observation of pronounced differences between students taught biology traditionally and those taught with a series of active, inquiry-based learning modules, termed “Workshop Biology.”

The Flipped (CLICed) Class as “Disruptive Innovation”

“I think [the traditional lecture] is going to be kind of blown away in favor of a model where every student is working at their own pace and the teacher now has a much higher-value role...”
- Khan, S. (2012)

“The key to the flipped class is actually not the videos, it is the freedom those videos give the teacher to have engaging class activities and interaction with their students.”
- Bergmann, J. (2011)

A method of introducing AL pedagogy in the undergraduate lecture hall that overcomes some of the barriers to its implementation is the approach known as class inversion or “flipping,” i.e. assigning material as homework that is usually covered in lecture and engaging students in AL during class.

This approach to classroom inversion is not new and there are many different models of class flipping. One model that has recently gained momentum has been popularized by Salman Khan (www.khanacademy.org). This approach, which I term CLIC Cinematic Lectures and Inverted Classes) in order to distinguish it from other flipping formats, relies on the delivery of course content through engaging, cinematic lectures (see Methods) outside of class, which enables the transformation of classrooms into arenas of inquiry and active learning (Figure 1).

![Figure 1. The CLIC model of course flipping.](image)

CLIC reform acknowledges the primacy of AL in reforming the traditional lecture class, but also recognizes the important role that faculty provide in creatively contextualizing course concepts within a large base of
knowledge. This idea has captured the attention of the educational and popular press\textsuperscript{12,60}, has been sweeping K-12 and educational communities, and is gaining popularity in post-secondary education.

In terms of online learning, CLIC can be viewed as a subset of those formats termed blended or hybrid, involving both online and face-to-face learning\textsuperscript{3,29,66}. There is substantial research in cognitive information processing\textsuperscript{79} and in evaluation of blended learning that supports the use of online multimedia in learning activities\textsuperscript{41,48,51}. Significant gains in learning outcomes for introductory biology students using multimedia vodcasts compared to those viewing class lecture-capture videos have been reported\textsuperscript{79}, and online prelectures followed by analytical problem solving in the classroom increased student understanding in introductory physics classes\textsuperscript{70}.

The theoretical advantages of CLIC for post-secondary education are pronounced. CLIC enables professors to deliver course content asynchronously to students who can engage the online cinematic lectures or cinelectures on their own terms, viewing them on computers or mobile devices at their own convenience and pace and, importantly, reviewing portions that they wish to understand more thoroughly at will. This, in turn, makes possible the transformation of lecture classes into venues where AL can be implemented. These two critical elements together can provide a more effective learning environment than the traditional lecture model. This game changing approach is a canonical example of “disruptive innovation”\textsuperscript{18}, that is being actively promoted by online teaching networks (e.g., www.flippedlearning.com; www.vodcasting.ning.com; www.flipteaching.com). CLIC has garnered some criticism. Most objections, however, concentrate on the inability of online video to engage students in inquiry-based activities\textsuperscript{59}, thereby ignoring the raison d’être of the CLIC approach.

Recognizing both the potential value of CLIC and the need for assessment of this type of reform at the undergraduate level, the author ran a pilot experiment in CLIC in the Fall 2011 semester and, based on these early results, has continued to improve implementation of the model in subsequent years. CLIC is still in very early phases of adoption at the university level, and other than the study of the effects of this model that we report here, the author is not aware of an assessment of this precise form of class flipping in an undergraduate, introductory biology class.

METHODS and IMPLEMENTATION

In 2011, two sections of an introductory biology lecture course (Introduction to Metabolism, Genes and Development\textsuperscript{5}), taught by the author, were run in parallel. One section (32 students) was taught in a long-established, traditional manner (TR), with lectures delivered during class, readings assigned in a textbook, and access to lecture graphics/slides provided via the online syllabus. The other, CLIC (CL) section (16 students) lacked both required reading assignments and in-class lectures. Instead, students were assigned online cinematic lectures (cinelectures) for viewing outside of class, but were encouraged to purchase an optional textbook for reference. The cinelectures, created with Camtasia software (Techsmith), were delivered via
links to YouTube from the course online syllabus. Despite a lack of individual student monitoring capability, YouTube was chosen over a traditional learning management system because of student familiarity with and access to this venue and because there is a need for engaging introductory biology content that can reach a diverse audience (at the time of this writing there have been over 180,000 views of Biology 122 cinelectures and many students from U.S. and international universities have expressed gratitude for these resources). The cinelectures incorporate multiple presentation media (e.g., see Figure 2). In developing cinelectures, critical design elements derived from empirical studies of online, multimedia educational projects were taken into account. The use of screencasting software permits the incorporation of genuine cinematic components into lectures. Examples include author generated molecular movies, avatars that interact with the lecturer, video clips that illustrate key points, and short video clips of other lecturers.

![Figure 2. Screen captures of three cinelecture frames showing a molecular model of ATP Synthase (left), screen work (middle), and a movie of lamellipodial extensions (right).](image)

In class, students in the CL section were broken into small groups and conducted AL activities that varied widely (e.g. building physical molecular models, constructing concept maps, designing plays to illustrate cellular mechanisms, formative assessments using clickers). Often groups of students or even individuals were responsible for presenting material to the class as a whole. AL modules were intended to provide opportunities for students to practice critical thinking about course content and to investigate and develop their understanding of key concepts. AL included the modalities of process-oriented, guided inquiry learning (POGIL – see http://www.pogil.org/post-secondary), peer-led team learning (PLTL – see http://www.pltl.org/) and problem-based learning (PBL), together referred to as PXnL.

In subsequent years, the CLIC model was employed exclusively for this same course, covering the same topics, and comparison to earlier learning outcomes were conducted. Analysis of learning outcomes in all cases was based on identical or lightly modified multiple choice tests and quizzes that included a range of questions spanning Bloom’s taxonomy scale. Comparisons between course sections utilized standard Student t-tests (e.g., see [Welch’s t test](http://en.wikipedia.org/wiki/Welch’s_t_test)) for learning outcomes, correlation analysis of science GPA and learning outcomes, and Likert scale course evaluations for student perceptions of their course experiences. One-way ANOVA comparisons and post-hoc Tukey HSD tests (e.g., see [Tukey HSD test](http://www.))
were used to compare learning outcomes over several semesters. Institutional Review Board approval for the use of student data was obtained (IRB number 2011028).

**PROJECT RESULTS**

*Parallel sections of Biology 122 (2011) – Traditional (TR) and CLICed (CL)*

There was no significant difference between the TR and CL sections in either overall or science GPAs (t-test, p>0.4, p>0.6, respectively), thus eliminating a potential confounding source of inter-section, academic aptitude variability. Accounting for all sources of content, the subject material covered was the same for both the TR and CL sections and assessments of learning were identical quizzes and examinations. Statistically significant differences in learning (quiz and test scores) were observed during the approximate first third of the semester (unpaired student t-tests, t=2.64, df=46, p<0.01), with the CLIC-class students performing better on all tests and quizzes in the period defined by Quiz 1–Exam 1 (Figure 3).

![Graph showing mean % of possible points obtained](image)

**Figure 3.** Mean % of possible points obtained in the Traditional (shaded) and CLICed (unshaded) sections of Biology 122 plotted for three periods defined by Quiz 1–Exam 1 (q1-e1), Quiz 5–Exam 2 (q5-e2), and Quiz 7–Exam 3 (q7-e3), and for the final exam and course totals. A significant difference between the sections was observed for the q1-e1 period. This difference disappeared for the remaining two periods, reappeared on the final exam, and, although not statistically significant, a pronounced difference was observed for the course totals. Error bars = 95% confidence intervals.

These differences disappeared in the remaining two periods of the course defined by Quiz 5-Exam 2 and Quiz 7-Exam 3 (Figure 3), and reappeared on the final exam. As expected based on previous data, a pronounced but non-significant difference in total course scores was observed (Figure 3) – see Discussion.

To investigate a possible reason for the lack of significant differences in learning outcomes in the last two periods of the semester, the number of course-generated cinelecture views was examined. These results are displayed in Figure 4. The loss of significant inter-section learning outcome differences in periods 2 and 3 (Figure 3) was observed to be coincident with a large increase in the number of university-originated views of
cinelectures. An anonymous, late mid-semester survey revealed that many of the students in the traditional class were using the cinelectures at this time, having added viewing of these to their study. This defect in the experiment provides an internal, if initially unintended, control (i.e., there was no apparent difference in comprehension ability between the sections). Although the “bleed through” of part of the experimental treatment (cinelecture viewing) to the control group (Traditional section) somewhat compromises the interpretation of the data so far presented, subsequent use of the CLIC approach in following years has yielded results that suggest a clearly positive effect of this pedagogy (see results below and Discussion).

The course that is the focus of this pedagogical experiment is notoriously difficult for students, especially the classical genetics section that spans periods two and three as defined in Figure 3. Many of our students give voice to frustration that, although they do well in other science classes, they seem to “underperform” Biology 122. In order to ascertain if CLICing might affect student performance in ways not immediately discernable by direct comparison of test scores, correlations between student science GPA and course learning outcomes were analyzed for the three course periods defined in Figure 3 and for the final exam and course totals. As can be seen in Figure 5, except for the final exam, the learning outcomes for students in the CLICed section are more closely correlated with their overall science GPA than those for the Traditional section, even for course periods in which learning outcomes did not differ significantly (Figure 3).
In the interest of gauging student perception of their learning experiences in both the Traditional and CLICed sections of Biology 122, CLU-standard anonymous university course evaluations were administered prior to the course final examination. Perceptions of some key learning indicators in the two sections differed dramatically (Figure 6). Students in the CLICed section rated their course higher in the following categories: use of effective teaching methods ($t=2.76$, $df=32$, $p<0.01$), usefulness of homework assignments ($t=3.01$, $df=24$, $p<0.01$), appropriateness of in-class activities for achieving learning objectives ($t=3.27$, $df=29$, $p<0.01$), explanation of course material ($t=2.10$, $df=32$, $p<0.05$), and course fostering of active participation ($t=5.15$, $df=32$, $p<0.001$).

**Figure 5.** For consenting students in the Traditional (——) and CLICed (- - -) sections of Biology 122, science GPA (x axis) is plotted vs the percent of possible points obtained (y axis) for the three course periods defined by Quiz 1 – Exam 1 (q1-e1), Quiz 5 – Exam 2 (q5-e2), and Quiz 7 – Exam 3 (q7-e3), and for the final exam and course totals. Correlation coefficients are presented in the top left of each panel.
Figure 6. Student perceptions of learning experiences in the Traditional (shaded) and CLICed (unshaded) sections of Biology 122 in 2011. Error bars = 95% confidence intervals.

Results with CLICed (CL) Biology 122 sections (2012 and 2013)

Since 2011, Biology 122 has been taught two full semesters and is currently being taught at the time of this writing (mid-semester). Although the results of the 2011 experiment were confounded by experimental “bleed-through” into the control (Traditional) section (see above), the results of exclusively employing the CLIC approach in subsequent semesters can be interpreted as having positive effects on student learning outcomes in this introductory course. Figure 7 compares the mean percentages of total course points for both 2011 sections and for CLICed sections taught in 2012 and 2013. A marked trend in higher scores is observed. A one way ANOVA comparison (p<.01) and post-hoc Tukey HSD test shows a significant difference between the 2011 Traditional and 2013 CLICed cohorts of students (p<.01).

Figure 7. Mean percent of total course points shown for the two Biology 122 2011 sections (TR and CL) and CLICed sections taught in 2012 and 2013. Error bars are 95% confidence limits.
DISCUSSION, REFLECTIONS, and FUTURE PLANS


There must be compelling and lofty motivations for undergraduate STEM faculty to institute significant pedagogical reforms in traditionally lecture-formatted courses, for such “disruptive innovation” is both challenging and time consuming. For example, in the present case, a 15 minute cinematic lecture might typically consume several hours of production and post-production (editing) work, and the development of quality active learning materials is not trivial. However, despite the formidable time investments involved, the extensive empirical literature that documents both the ineffectiveness of the traditional lecture and the positive effects on student learning that active learning engenders provides these motivations for reform-minded faculty (see Introduction). Active learning in the lecture hall makes tangible the “Carnegie Hall Hypothesis,” using valuable, in-class “seat time” to promote high-order cognition and metacognition through the practice of critical thinking. This practice promises to increase student learning, enhance retention of students from underrepresented groups, and help dampen the attrition of STEM majors, a disturbing national trend that is projected to result in a 1,000,000 shortfall in STEM-educated graduates over the next decade.

Despite its documented value, there remain formidable barriers to widespread incorporation of active learning in the classroom, and traditional lectures remain the norm for most introductory science classes. These barriers include academic cultures that sometimes undervalue teaching innovations, professorial habits revolving around lecturer-centered education, perceptions of professional identity that conflict with pedagogical reform, the necessity of delivering copious amounts of content in a single quarter or semester, the perceived efficiency of lecturing to students in notoriously large introductory classes, lack of time and institutional incentives, and even student skepticism regarding the value of and participation in active learning. One other major barrier is the understandable desire of faculty to provide individualized frameworks for course topics that go beyond standard textbook explanations, frameworks that have traditionally been delivered exclusively by in-class lectures.

The model of classroom flipping that is the subject of this report can be used to overcome this last, but important, barrier. The use of cinematic lectures (cinelectures) allows professors to construct their own, individualized conceptual framework for course topics that can be assigned as out-of-class work (even replacing textbook readings) and opens the door for the extensive implementation of active learning modules in the lecture hall.

Several advantages of the cinelecture component of CLIC are noted:

- The four P’s of student accessibility ³ are met: PLACE (students have the flexibility to learn in a location of their own choosing); PACE (students can learn at the speed suited to them); PEACE (students can determine the time in which they learn); PROCESS (students may skip topics they are confident with and concentrate on unfamiliar topics, reviewing them at will);
Video clips of external lecturers may be captured and inserted into a given cinelecture (e.g., www.genome.gov/Glossary). This allows the use of public domain lecture clips of women scientists and of those from under-represented demographic groups. This “virtual diversity” in role model lecturers may serve as an important contribution in reaching students from under-represented groups;

Videos, animations, and simulations that are difficult for students to absorb when receiving them as a “one-off” experience in a traditional lecture are much more comprehensible when available online;

Students are more likely to engage in the requisite 2 hours of homework for every 1 hour of class time as suggested by the Carnegie Foundation and the Department of Education when their out-of-class work can be monitored and involves viewing engaging videos;

Unlike textbook reading followed by traditional lecture, the importance of cinelectures in the enhanced learning environment of a CLICed classroom incentivizes students to view them prior to coming to class, due largely to peer pressure from small group members with whom they interact in most active learning modules;

Many introductory STEM courses are delivered by adjunct or part time professors who lack time and resources to undertake their own cinematic productions, but the creation of a wide variety of cinelectures by teams of faculty, coupled with associated active learning suggestions, could provide adjuncts the means and resources to introduce active learning in their classrooms.

The results of the 2011 pedagogical experiment in which sections of a Traditional and CLICed introductory biology course were run in parallel were confounded by experimental bleed-through, in the form of students in the Traditional class engaging in cinelecture viewing during the last two thirds of the semester. However, significant differences between sections were observed in the first period of the semester, when cinelecture views primarily derived from CLICed section students. Although this latter result is positive, it is nevertheless disturbing because the learning outcome differences obtained could be interpreted as arising from cinelectures alone, irrespective of the active learning modules that were implemented in the CLICed section, given the lack of significant differences in the latter two thirds of the semester. Nevertheless, the stronger correlation between science GPA and learning outcomes observed for students in the CLICed format throughout most of the semester suggests some positive impact of active learning.

I attribute the significant increased learning outcomes in Biology 122 sections taught since 2011 to be the result of augmentation of the active learning modules that students now engage in as result of my continually increasing experience in developing high order cognitive questions, activities that promote metacognition, and group activities that are more engaging for students. For one example, employing techniques of scientific teaching, students use clickers to answer a high order cognitive problem and look at the results of the e-poll together. Then they talk in small groups and vote again, which often generates peer-to-peer conversations that alert both students and the author to prominent misconceptions that can be addressed on the spot. A second example employs student directed theatre, in which students act out a particular process, say the regulation of the lactose operon (gene regulation), and then adapt their “plays” to different molecular scenarios. This requires a thorough understanding of the underlying biology and motivates
students to apply existing knowledge to new situations. Increasingly, as a result of improved active learning opportunities, I observe students thinking about what they do and do not understand and expressing formulated questions based on this increased metacognition. This is a phenomenon I have rarely, if ever, observed in traditional, introductory, lecture-based classes.

Based on results of course evaluations presented above, and subsequent course evaluations, I can confidently state that most students take well to CLICed pedagogy. Indeed, it is clear from the heavy use of cinelectures by students in the 2011 traditional course section that asynchronous, video-based lecture material is preferred over textbook reading by many students. In past years, although some of my most academically prepared students were comfortable synthesizing information from lectures and readings and applying it critically as demonstrated by test results, I was always disappointed in the lack of deep learning for a significant plurality of my students in traditionally taught lectures. CLICing is serving to remedy this and I am committed to continuing the development of both high quality cinelectures and active learning modules.

There is no question that whole scale conversion of a traditional lecture class to a CLICed format is an ambitious undertaking, especially if a faculty member launches such a project independently, as was done in the present case. The production of high quality cinematic lectures along with the development of effective active learning exercises should be undertaken as a long-term project with the understanding that a thorough transformation of a traditional lecture hall into an arena of inquiry is an ongoing, iterative process. For readers who are contemplating instituting a CLIC model of classroom flipping, several suggestions are in order: 1) if your institution has a teaching and learning center with staff who are familiar with screencasting methods, seek their help in producing cinematic lectures; 2) spend some time researching active learning resources that may be freely available for your discipline; 3) start small – try to create one or two cinelectures and associated active learning modules in order to flip a small section of an existing course, and expand this approach incrementally.

REFERENCES CITED

1. The term active learning (AL) may acquire different, contextual meanings, but it is generally understood as pedagogy in which students are encouraged to develop their learning autonomously. AL requires students to ask questions of themselves and their peers in solving problems, in contrast to passively receiving information. Process-oriented, guided inquiry learning (POGIL), peer-led team learning (PLTL), problem-based learning (PBL), and Investigative Case Based Learning (ICBL) are often components of an AL environment (e.g. see reference 26).

2. Introduction to Metabolism, Genes and Development, “The Flow of Life.” This course introduces energy flow within cells, mechanisms of heredity, the expression of genetic information, and the means by which genes encode developmental programs. Emphasis is placed on the concept that genetic mechanisms and developmental controls reveal a fundamental kinship of all life. The tools of genetics, including mutational analysis of model organisms, recombinant DNA, and biotechnology are introduced.


Hagood Comments: This is an impressive case study. I particularly appreciate the care that was obviously taken in conducting the experiment at hand and in analyzing the results. The graphics are excellent, as is the theoretical grounding.

However, I found myself wanting more information about what I believe to be some important aspects of the transformation into a cinelecture class, including the role that the textbook did or did not continue to play in the cinelecture version of the course, the choice to make cinelectures accessible through YouTube rather than a learning management system; and how cinelectures were actually made. You make the important point that, to be most effective, a cinelecture should not simply be a video recording of a typical lecture. But what, then, should it be? What should others who may be contemplating flipping their STEM classes know about how to put together effective cinelecture resources, and how much of a time commitment is it to fully flip a course?

The case study does a superb job of considering the effect of this new course delivery system on student learning outcomes, and while that might be the most important consideration for our readers, it will be leavened by other important factors including how achievable creating cinelectures seems. When the case study includes some more extensive discussion of these factors, I believe it will feel more complete and be even more appealing to our readers.

Recommendations: Case study is compelling and well written, but should include some additional discussion of implementation through an additional revision.

Pang Comments: I’ve suggested some copy edits and made a few requests for clarification via my marginal comments. Regarding style, I want to note that Chicago style does provide an author-date documentation system, the use of which seems more appropriate here than the notes and bibliography system generally preferred by humanists. I noticed that the first draft used author-date citation, and think it ought to be reintroduced here. I regret not making clear that both options are available to authors, depending on their disciplinary backgrounds!

On a more substantive level, I really appreciated this case study’s intense focus on learning outcomes and its rigorous comparison of teaching methodologies. In this way, it offers a unique perspective quite different from other case studies submitted. There are a few places where adding brief explanations or restating points for the sake of clarity will aid non-STEM readers in following the case presented. That said, I (happily) expect that those from STEM disciplines will appreciate the discursive approach.

I do agree that the case study will be even more useful to readers if it explains how exactly the author (and any collaborators with whom he may have worked) actually went about producing and delivering the core course elements – especially cinelectures, but also active learning activities – that he later went on to evaluate as described in the case. For those looking to replicate the results described, such information will be essential.