From Flipped to Open Instruction: The Mechanics Online Course

Colin Fredericks[1], Saif Rayyan[1], Raluca Teodorescu[1,2], Trevor Balint[2], Daniel Seaton[1], and David E. Pritchard[1]
[1]*RELATE Group, Massachusetts Institute of Technology,* [2]*George Washington University*
cfred@mit.edu, srayyan@mit.edu, rteodore@gwu.edu, tabalint@gwu.edu, dseaton@mit.edu, dpritch@mit.edu

Abstract

We describe the development of the Mechanics ReView and Mechanics Online courses. In the first half of the paper we present the history and operation of these courses. We describe the impact of several features, including the use of frequent and embedded assessment to improve e-text reading rates, and multiple explicit levels of homework problem to target students of varying skill levels. In the second half of the paper we give special attention to the most recent versions of the course: an online course in the spring of 2012 oriented toward those seeking a review of introductory mechanics, and one in the summer of that year primarily advertised towards teachers. Comparing and contrasting the two courses shows how changes in the audience, timing, and structure of a course can alter certain outcomes (e.g. attrition rate, reaction to frustration) while leaving others (e.g. student opinions of various course components) almost untouched. Especially notable is the improvement in student retention of students who attempted at least part of the second assignment from 44% to 74%, a value typical of elective on-campus courses. The course will be offered again in summer 2013. (http://RELATE.MIT.edu/physicscourse).

1. The History of Mechanics ReView

Mechanics ReView was initially developed as a reformed on-campus course with online materials that enable a flipped classroom (where in-class time is spent on problems and acquiring new information is done primarily at home). This evolved into an open online course, Mechanics Online. This progression is in contrast to most current-generation MOOCS, which are built for online use, generally resemble traditional on-campus courses, and are now touted as vehicles to reform on-campus education by flipping the classroom.

The impetus for Mechanics ReView was a common student plea for help: “I’ve read the book, I understand what was said in class, but I can’t start the problems.” From a cognitive perspective, textbooks teach declarative and procedural knowledge, assuming that the students will learn strategic knowledge by themselves. Many traditional lecture-based courses do the same. To help students learn strategic knowledge, the RELATE group developed a pedagogy called Modeling Applied to Problem Solving (MAPS).

MAPS is a strategic, systematic approach to problem-solving based on categorization of student knowledge into models. The basic knowledge of Mechanics is represented as five core models (similar to but distinct from the models separately developed by Hestenes[1]). Each model specifies the types of system to which it applies, the interactions that change the variable of interest (velocity, momentum, mechanical energy, angular velocity, or angular momentum) and the equation governing that change. Students are then taught a systematic approach to problem solving called SIM, for System, Interaction, and Model. SIM tells students to plan a solution based on explicitly picking a System, identifying the important Interactions, and selecting an appropriate core Model.

MAPS was first implemented during Mechanics ReView, a short course during MIT's January term. Students in this course had received a D in MIT's introductory mechanics course the previous Fall. The course ran for three weeks of classes, two hours per day. In this time, Mechanics ReView brought the class average on a precalibrated final exam from the D the students had received in December up to the class average. Eighty percent of course time was spent with students working at the whiteboard in pairs on multi-concept problems while staff members circulated to help and challenge them. The remaining 20% was instructor comments and some preplanned group activities interspersed through the classes. This approach has recently been called the "flipped classroom." The Colorado Learning Attitudes toward Science Survey indicated an increase of nearly 15% in the expertise of the students' attitudes towards learning science (as opposed to the 10% reduction typically observed in large introductory courses, including MIT's own). This was described in detail at PERC 2009 [2]. Moreover, these students' performances in the following Electricity and Magnetism course exceeded a prediction based on their fall term grade by half a standard deviation, relative both to students not taking the ReView and to those required to take an additional semester of introductory mechanics. [3].

To help with this ReView, postdoc Andrew Pawl led the RELATE group to create online resources [4] containing explanations of the models, how they interrelate, many worked examples using the SIM approach, and a glossary. These formed the basis of our current e-text.

When the January course proved to be effective, the Spring introductory mechanics course – a full-semester course mainly targeting students who failed or dropped the fall course – was reformed using the MAPS pedagogy. In order to teach students with a weaker background in mechanics, a complete online e-text was created by adding the principal topics in the standard introductory mechanics syllabus. Each major topic was presented as a core model, illustrated by worked examples using the SIM approach.

To better prepare students for class, we added computer-graded homework to this e-text by moving it on to the LON-CAPA platform [5]. A substantial amount of the course's written homework was replaced with online homework, with about one third of the new problems coming from the LON-CAPA library. Details on the goals and design of this environment were presented at PERC 2010 [6].

In the transition from Mechanics ReView to Mechanics Online we intended to create an open online course that remained suitable for a flipped classroom. For this reason, the course was based on both our classroom experience and relevant research findings. We embedded checkpoints in our text and shortened text pages to enhance participants' reading experience. In writing our e-text we paid close attention to novices' documented misconceptions and difficulties with fundamental concepts. The e-text was further informed by feedback received from on-campus students answering reading questions. Additionally, we embedded the text with resources like PhETs [7] that have been proven to stimulate learning.

This work allowed us to address an important long-term goal for our group: creating a free open-source online learning environment for mechanics. Given that the online students lacked class sessions to clarify the e-text, we added checkpoint questions between and sometimes within the e-text modules (they were used in the on-campus course in spring 2012 as well). Our online course was entitled Mechanics Online and was first offered in the spring of 2012, and again in the summer of that year. We present some of the significant findings from those courses and the differences between them later in this paper.

Mechanics Online has recently been moved to the edX platform, and is being tested in this spring's on-campus course. (The process involved replacing many LON-CAPA problems, as we did not have author permission for the use of those problems outside LON-CAPA.) A stand-alone version of Mechanics Online will be offered in the summer of 2013 as Mechanics ReView, with increased emphasis on the MAPS pedagogy and publicity aimed at attracting teachers.

2. How Mechanics Online Works

Mechanics Online is organized into units and modules, in the same way that a textbook is organized into chapters and subchapters. Each module consists of web pages with instructional content, videos, and worked examples. Checkpoint questions, generally considered easier than the homework questions, are interspersed through most modules. Homework questions of varying difficulty (see section 2.1) are found at the end of each unit. These problems require participants to choose an answer or enter a numeric or symbolic response. Multiple attempts are allowed. The answers to all homework problems are displayed after the due date. Tools on the site allow participants to check on their progress. Although participants can navigate the course resources in any order, most follow the course sequence quite closely through each unit but skip around in the homework.

Grades were calculated based on two measures: checkpoint questions and homework. In the online course there were also quizzes at the end of most units. Interweaving instruction and assessment in this course was an intentional choice: frequent exams have been shown to substantially increase the amount of material that students read or view in a course [8], as well as having other desirable effects such as reducing cheating [9]. Courses with frequent assessment can see 80% of students reading 80% of the available text.

Participants had access to discussions at the bottom of each page, where they could post questions, answers or comments. Participants used these to discuss problems and concepts with each other, and to alert course staff about issues with the material. Staff intervention in these discussions was kept to a minimum, and course staff only stepped in when forum-goers gave answers to the homework directly (uncommon) or became uncivil (very rare).

2.1 Homework With Different Level Problems

Homework was presented at three levels. Level 1 problems (1 point each) typically involve just a single concept or calculation. Level 2 problems (2 points) involve more than one concept or more involved mathematics. MIT Exam Level problems (3 points) have additional complexity and challenges. Participants were required to obtain 15 points per unit, from any combination of problems whose point total was typically ~ 45 points. This scheme allowed weaker participants to earn full credit without attempting MIT-level problems, while providing rewarding challenges to participants with stronger physics skill.

Scores and times for these problem types and for the checkpoint problems were analyzed for the on-campus spring 2012 course. (We are performing similar analyses for the Mechanics Online course.) Clear differences between the problem types can be seen in the mean scores, as well as on student-averaged median times for a first attempt – see Figure 1. We were surprised to see that the probability of mean percent correct varied only between 40% and 60%, but the time varied between ~75 and ~200 seconds. Rather than rewarding skill, we were primarily rewarding time spent on the problems [10].

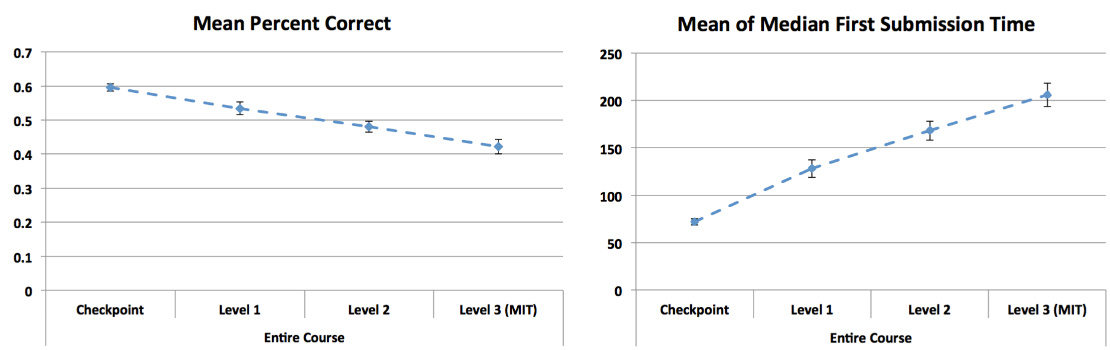

Figure 1. Mean percent correct by problem type, and median time (in seconds) to first attempt. Dashed lines guide the eye. Data from spring 2012 on-campus course

3. Comparison Between Spring and Summer Courses

The spring and summer offerings of Mechanics Online were offered in the same format, on the same platform (LON-CAPA), with a nearly identical set of resources and problems. The summer course offered greater flexibility of its schedule: materials were posted many weeks in advance, and the test deadline was extended 1 week past the homework deadline. Participants were able to work ahead and complete material early if they needed to clear time for a vacation.

Due to the large number of teachers in our spring course the summer course was advertised to (and successfully attracted) physics teachers, whose demographic impact was significant. Details can be found in Section 3.2.

The strong similarity of content in the two courses allowed us to better examine the effects of the few differences that did exist. Information about the courses comes both from survey information and analysis of data gathered by the LON-CAPA platform.

3.1 Enrollees and Persistence

The spring course had an initial registration of 2240, ~400 of whom attempted at least one question in the course. 55 participants were issued a certificate. The summer course had fewer registrants: 850, ~280 of whom attempted at least one question. However, 117 of them received certificates, substantially more than in the spring. Comparing participants who attempted at least 25% of the second homework to those who received certificates, the summer course's retention rate was 74%, whereas the spring's was 44%. Figure 2 illustrates retention in these two courses. The plot shows how many participants registered, attempted any course activities, completed the second homework, or passed the halfway mark for every one participant who received a certificate. MITX's Circuits and Electronics, or 6.002x, a MOOC that attracted ~150,000 registrants and gave 7,158 certificates, is included for comparison.

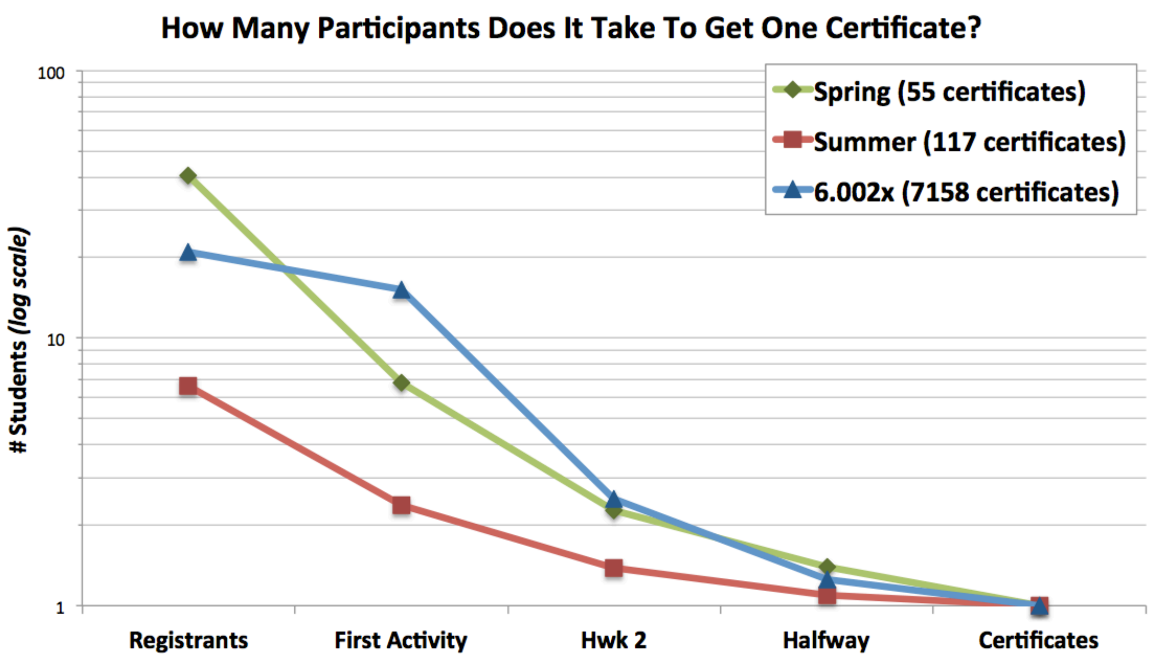

Figure 2: Number of participants active at certain stages of the course for each student who received a certificate. Note the logarithmic scale.

There are several possible reasons for this increase in retention. First, participants may have appreciated the extra flexibility in the course's timing. Second, the greater percentage of teachers in the course may have resulted in a course demographic more prone to academic persistence. Third, The summer version made the last 3 units in the course optional (out of 14 units), which may have let some people finish who otherwise would not have. A combination of these factors seems likely.

3.2 Who were our enrollees?

Two surveys were given in each online course: one in the first week of the term, and one after the last week. Approximately 300 participants answered the beginning-of-term survey in the spring, compared with 440 in the summer. About 50 participants answered the end-of-term survey in the spring, with 70 responding in the summer.

Figure 3 shows the level of physics knowledge of enrollees who responded to our initial survey in the spring and summer courses. We were surprised at the large fraction of physics teachers who enrolled in our spring course. This led us to intentionally market the summer course toward physics teachers. Our goals were not merely to increase numbers through targeted marketing, but also to help teachers and to efficiently spread MAPS pedagogy. Continuing Education Units for American high school teachers were also arranged through the American Association of Physics Teachers. Over 45% of the summer enrollees who answered the survey were physics teachers and ~ 90% of the certificate recipients were teachers (about two thirds high school and one third college).

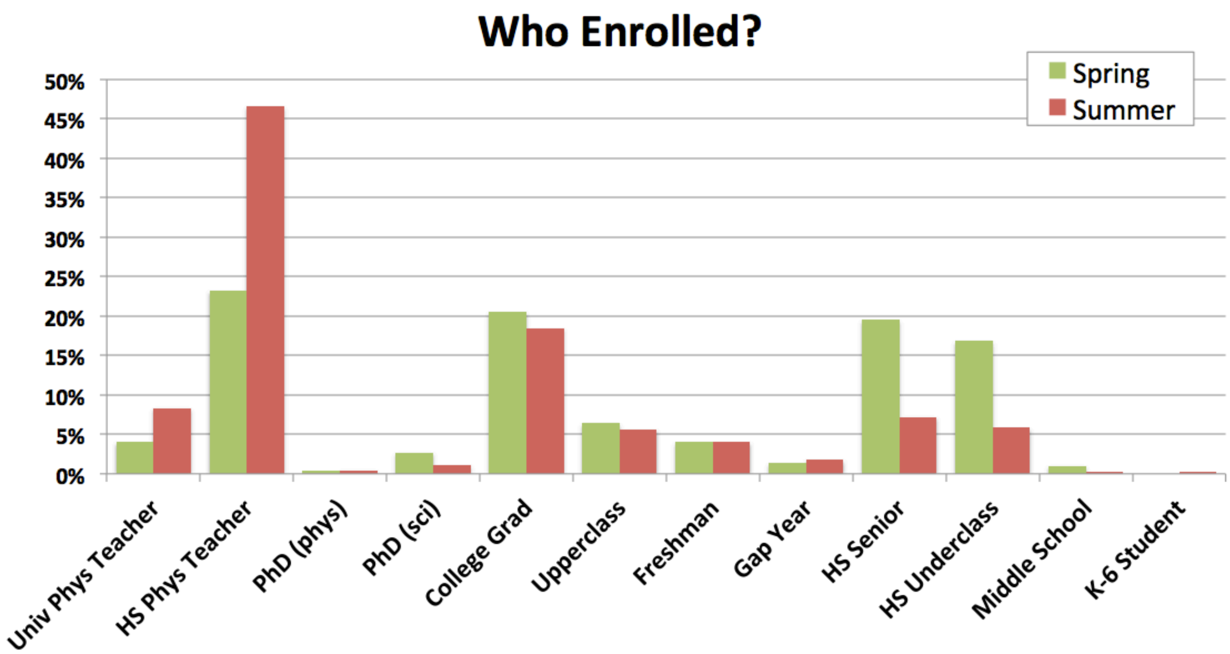

Figure 3. Enrollees in Mechanics Online

As one would expect, enrollees in the summer course had generally taken more than one year of college physics, whereas those in the spring generally had not. Mathematics proficiency was also higher among the summer participants.

3.3 End of Term Surveys

The spring and summer end-of-course surveys showed agreement on many points. Participants appreciated the course for its many high-quality challenging problems. They found the homework absolutely essential to the course. Many also found the discussion boards to be very useful and the discourse there of high quality. On the negative side, there were complaints about the interface in LON-CAPA, some related to navigation and others related to the method of inputting equations. Many participants also expressed a desire for more time, and (especially in the spring) for greater flexibility in the schedule of the course. Others were interested in having particular resources available, such as detailed solutions, sample problems, or improved discussion forums.

Survey respondents listed two main reasons for taking the course: "Interest Only," and to "Review Physics." Other options presented in the survey included preparation for AP exams, for advanced standing exams, or "other." More spring participants were taking the course for their own interest only, while more summer participants were there to review physics.

Relative to spring, summer participants found the course to require more independence. They also exercised more independence when stuck. One survey question asked respondents what they did when they were "stuck, frustrated, or had a question." Summer participants gave an average of 2.0 responses each (citing such actions as taking a break, checking in a textbook, using the discussion forums, or checking elsewhere online) vs. 1.4 responses for spring. (This aligns well with survey data taken from physics courses using online homework at UMass Amherst [11], where a greater number of responses were seen in a course for physics majors than in a calculus-based service course.) Correspondingly, the spring participants both found the homework more indispensable and appreciated the MAPS pedagogy more than the summer participants. Summer participants, meanwhile, were more likely to be satisfied with their understanding of the material at the end of the course.

3.4 Completion Certificates and Teacher Certification

Participants who completed Mechanics Online with a certain percentage were issued a certificate. These showed participants the number of points they earned on homework, their percentage on the quizzes, and their total time spent in the course, both in absolute terms and relative to the rest of the class.

The range of times actually spent on the course by these individuals was substantial. The median time spent by certificate earners was 43.7 hours, with a standard deviation of 25.9 hours. To highlight a dramatic example, one participant spent only 7 hours in the course and achieved a score of 59%, while another spent 106 hours to achieve a 58%. An examination of survey responses showed that even participants who completed the course were not accurately able to estimate the amount of time they would need to spend in the course each week.

High school teachers from the USA who took Mechanics Online in the summer of 2012 were also able to obtain Continuing Education Unit certificates from the American Association of Physics Teachers. Because of the interest in this certificate, the RELATE group later became certified to offer similar certificates for the state of Massachusetts.

3.5 Lessons Learned

We pause here to describe two missteps in developing Mechanics Online, in the hopes that others can benefit from our negative results.

First, during the Spring Mechanics Online, course content was initially released one week at a time. Quizzes were only visible for 33 hours, from Friday noon to Saturday evening. Participants had 3 hours from the time they opened the quiz to complete it. Several participants complained about the limited time of the quiz, and asked for more flexibility with material release and with quiz schedule.

For the summer release, course material, including quizzes, was released in advance (1/3 of the course was released at launch, 1/3 after 2 weeks, and 1/3 after 4 weeks) to allow participants to plan ahead around the due dates. Quizzes were timed, so that participants still only had 3 hours to finish the quiz (and could only attempt the quiz once), but the quizzes were open as soon as the associated material was released and participants could attempt them at any time. We suspect a positive effect from this change on retention, as the summer survey showed fewer complaints about the tightness of the schedule.

Second, the summer 2012 offering of Mechanics Online included online "office hours" shown live via Google Hangouts. Participants in the course were encouraged to submit questions on each week's material via discussion board, as well as to vote up the questions they wanted to see answered. They could then view the professor or other course staff discussing the questions with a pair of undergraduates during "office hours." The goal was to create a tutoring-like environment, to improve student understanding [12]. Unfortunately the highest live viewership was 2, numerous technical problems plagued the video broadcasting, and the office hour videos were ranked significantly below other videos on the end-of-term survey. Substantial retaking, reviewing, and editing time was invested to make these into modular discussions of each question, which seem valuable to us. However, in retrospect it would have been preferable to prerecord office hour videos. Quality would have been higher, and thought could have been given to making them more reusable even if the particular homework question they involve is not used in the course in future years.

4. Summary and Future Goals

In this paper we have discussed a calculus-based open online mechanics course that can also be used in flipped classroom instruction. Unlike most online learning environments, this course was developed from online materials created for an on-campus course. This on-campus course teaches a standard mechanics syllabus using a flipped classroom with a new pedagogy (MAPS) that is designed to increase student expertise in problem solving.

This online course met our objectives: increasing both students' expertise about learning, and their problem-solving ability, in a way that carries forward to their subsequent physics course. These objectives were achieved through construction of a complete set of research-based online resources centered on a short e-text. This course has been subsequently improved by adding additional videos and problems. The course's homework has recently been enhanced with research-based problems similar to those found in TIPERS [13] and the Mechanics Reasoning Inventory [14].

Several research opportunities present themselves as we move to future versions of the course. The greater number of participants that seems likely with edX not only allows for greater accuracy in statistical measurements, but also makes new statistical approaches possible. We hope to use Multidimensional Item Response Theory to examine student skill and problem difficulty along several axes, which will enable us to determine whether the various types of research-based problems actually present significantly different challenges to students. We hope that implementing Bayesian Knowledge Tracing will enable us to determine which elements of the course help students learn most effectively.

4.1 The Benefits of Teaching Teachers

Survey results showed that physics teachers were a large component of our Spring 2012 course. Therefore, we advertised our Summer 2012 course to attract teachers. We ran advertisements in the National Science Teachers Association's "NSTA Express" e-mail newsletter, in the AAPT's "eNNOUNCER" e-mail newsletter, and posted on various free event calendars.

Marketing the course to a particular audience (especially *this* particular audience) seemed very successful. More certificates were awarded in the summer than in spring, with 90% going to teachers. The appreciation that teachers had for Mechanics Online was attested to by the many who requested copies of the homework, quiz problems, and other online materials for use in their own courses. We believe that such specialization has contributed to the low attrition rate observed in the summer course. We speculate that the plethora of open online courses currently being developed and deployed will ultimately be adapted and targeted to specialized audiences, and that when this happens their attrition rates will decrease.

Creating an open online course may have more than just philanthropic benefit. We suspect that teachers also appreciated the opportunity to obtain continuing education units without the hassle of attending a workshop that might last for a week or more. Institutions interested in spreading the use of a particular technique, pedagogy, or set of materials have the opportunity to build strong relationships with teachers by presenting those materials for free. Our group sees a tremendous benefit to our objective of spreading our MAPS pedagogy and materials to the many high school and college students whom each teacher reaches each year.

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6. References

1. See for example D. Hestenes (1997), *Modeling Methodology for Physics Teachers*. In E. Redish and J. Rigden (Eds.) The changing role of the physics department in modern universities, American Institute of Physics Part II. pp. 935–957

2. Pawl, A., Barrantes, A., & Pritchard, D. (2009). *Modeling Applied to Problem Solving*. Proceedings of the 2009 Physics Education Research Conference, M. Sabella, C. Henderson and C. Singh, (Eds.) pp. 51-54

3. Rayyan, S., Pawl, A., Barrantes, A., Teodorescu, R., & Pritchard, D. (2010). *Improved Student Performance In Electricity And Magnetism Following Prior MAPS Instruction In Mechanics*. Physics Education Research Conference 2010 Portland Oregon, AIP Conf. Proc. 1289, 273(2010).

4. https://wikis.mit.edu/confluence/display/relate , retrieved on March 20th, 2013

5. The Learning Online Network using a Computer-Assisted Personalized Approach. http://www.lon-capa.org

6. Teodorescu, R., Pawl, A., Rayyan, S., Barrantes, A., and Pritchard, D. (2010) *Toward an Integrated Online Learning Environment*. Physics Education Research Conference 2010 Portland Oregon, AIP Conf. Proc. 1289, 321(2010). (Refereed)

7. Perkins, K., Adams, W., Dubson, M., Finkelstein, N., Reid, S., Wieman, C., & LeMaster, R. (2006) *PhET: Interactive Simulations for Teaching and Learning Physics*. The Physics Teacher, 44:1, pp. 18

8. Seaton, D., Bergner, Y., Pritchard, D. *Exploring the relationship between course structure and etext usage in blended and open online courses*. (Submitted 2013)

9. Laverty, J. T., Bauer, W., Kortemeyer, G., & Westfall, G. (2012). *Want to Reduce Guessing and Cheating While Making Students Happier? Give More Exams!*. Physics Teacher, 50(9), 540.

10. Teodorescu, R., Seaton, D., Cardamone, C., Rayyan, S., Abbott, J., Barrantes, A., Pawl, A., & Pritchard, D. (2011). *When Students Can Choose Easy, Medium, or Hard Homework Problems*. Physics Education Research Conference 2011, AIP Conference Proceedings to be published

11. Fredericks, C. (2007) *Patterns of behavior in online homework for introductory physics*. PhD Thesis, University of Massachusetts Amherst

12. Craig, S., Chi, M.T.H., & VanLehn, K. (2009). *Improving classroom learning by collaboratively observing human tutoring videos while problem solving*. Journal of Educational Psychology 101: 4, 779-789.

13. Maloney, D., Hieggelke, C., & Kanim, S. (2010, July 21-22). *nTIPERs: Tasks to Help Students "Unpack" Aspects of Newtonian Mechanics*. Paper presented at Physics Education Research Conference 2010, Portland, Oregon.

14. Pawl, A., Barrantes, A., Cardamone, C., Rayyan, S., & Pritchard, D. (2010). *Development of a Mechanics Reasoning Inventory*. Physics Education Research Conference 2010, AIP Conf. Proc. 1289, 273(2010).