Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course

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Comparing the Effectiveness of an Inverted Classroom to a Traditional Classroom in an Upper-Division Engineering Course

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***Abstract*—An inverted, or flipped, classroom, where content delivery includes video lectures watched outside of the classroom, is a method that can free classroom time for learner-centered activities such as active and problem-based learning. This study compared the effectiveness of an inverted classroom to a traditional classroom in three areas: 1) content coverage; 2) student performance on traditional quizzes and exam problems; and 3) student observations and perception of the inverted classroom format. A control-treatment experiment comparing an inverted classroom to a traditional lecture-style format was used. The results show that: 1) the inverted classroom allowed the instructor to cover more material; 2) students participating in the inverted classroom performed as well or better on comparable quiz and exam questions and on open-ended design problems; and 3) while students initially struggled with the new format, they adapted quickly and found the inverted classroom format to be satisfactory and effective.**

***Index Terms*—Active learning, control systems, education, flipped classroom, inverted classroom, problem-solving, semi-supervised learning.**

I. Introduction

THE PRESSING need to reengineer engineering education has been established in the past decade [1]–[4]. Yet, engineering education today is still largely using outdated approaches for teaching technical concepts and problem solving [5]. Developing skills that are conducive to professional success is a key factor behind the emerging shift away from a traditional lecture–example–homework format to more applied, learner-centered classroom [6]–[11]. The learner-centered classroom, however, imposes difficulty for educators because they need to make time for methods such as active and problem-based learning while still meeting the heavy content demands of engineering courses [12], [13]. One promising approach is to deliver the course content using an inverted (i.e., flipped) classroom and so free class time for active and problem-based learning [14]–[16].

In an inverted classroom (IC), course content is disseminated outside the classroom through traditional formats such as assigned reading and homework problems and through new formats such as video lectures, PowerPoint presentations, and Web-based tutorials. The IC has been enabled by the advent of digital video recording, digital media, and interactive Web pages. These resources allow instructors to capture and publish course content online where they are easily accessible to students outside of class time. Unlike an online class, an IC includes face-to-face time with the instructor in a classroom or laboratory setting where the material learned outside of class is discussed and applied.

There are three primary motivations for using an IC. First, the IC frees class time for interactive activities, such as active, cooperative, and problem-based learning, and for reinforcing course material without sacrificing content [13], [16]–[21]. Second, the IC allows an educator to present course material in several different formats, and so engage the students' various learning styles and preferences [13], [22]. Third, the IC can encourage students to become self-learners and help prepare them for how they will need to learn as practicing engineers [17].

Although there are compelling reasons to implement an IC, there are also some potential problems. First, implementing an IC can initially be time-consuming. An instructor cannot simply videotape a 50-min lecture. Zappe [13] found an optimum video length to be around 20 min, which requires the instructor to reorganize course material into short segments and to spend time editing recordings. The instructor must also develop and include activities and/or a pretest to ensure that students are prepared for class [18], [23]. Second, online learning may frustrate some students. Strayer [24] found some students were uncomfortable at having to take responsibility for their own learning. The instructor can allay this discomfort by providing clear expectations for what students should know [25]. Third, there is some discrepancy in the literature about the appropriateness of an IC for different course levels. Bland [17] was cautious about using an IC in more advanced courses, while others suggest that an IC may be more applicable in advanced courses [24], [26].

This paper reports on the results of a two-year study in an upper-division engineering course in which a traditional lecture course (TC) was used in one year and an IC was used the next. The goals of the study were the following.

1) To quantify how an IC affects classroom management—specifically content coverage. Although others [17] report that an IC allows the use of student-centered learning in the classroom without sacrificing content coverage, the results are primarily based on observation and not on a direct comparison to an identical course in a controlled setting.

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2) To evaluate how the IC, when coupled with cooperative and problem-based learning, affects student understanding of course material. Performance on traditional textbook problems of students in an IC was compared to those in a TC. Since students wishing to pursue engineering licensure (Fundamentals of Engineering and Professional Engineering exams) must pass a test composed of traditional textbook-type problems, it is important that the IC not sacrifice student performance on such problems. This issue has been investigated in several studies, although none of these deals with an upper-division engineering course [16], [23], [26].
3) To assess student perceptions of the IC format in an upper division class. Researchers report high student satisfaction with an IC format in lower-division courses [16], [17], [23]. However, researchers are divided on the use of an IC in upper-division courses.

It is important to recognize that the study discussed here did not attempt to differentiate the effects of active, cooperative, and problem-based learning and an IC. The IC is viewed as a delivery mode for learner-centered activities in the classroom.

II. Method

A Control Systems course in the Department of Mechanical Engineering at Seattle University, Seattle, WA, USA, was used for this study. The course, required of all seniors in the mechanical engineering program and an elective course for senior electrical engineering students, was taught over 10 weeks as a four-credit quarter-long course. The course is the students' first exposure to control systems concepts in the curriculum; it follows a traditional control system textbook [27] applicable to both electrical and mechanical engineering programs and covers root locus, Bode plots, Nyquist plots, proportional-integral-derivative (PID), lead/lag controllers, and state-space design.

The course was evaluated in two successive years, the first of which used a TC and the second an IC. Both courses were taught in winter quarters, four days a week (200 min of in-class time per week) in the same time-slot, by the same professor, using the same textbook and weekly homework assignments. Topics were introduced in the same order and exams scheduled at approximately the same time during the quarter. In both courses, students were assessed using weekly 15-min quizzes, a 50-min midterm exam, and a 110-min final exam. Assessments were similar in both years, each having approximately the same number, type, and difficulty of questions. Both courses used MATLAB's control system software and control system hardware developed by Quanser [29]. Students were expected to read the textbook, do homework, solve problem examples, and take sample quizzes outside of class time in both courses.

A. Traditional Lecture Classroom

The Control Systems course was taught in the first year using a traditional lecture format (TC). The class was composed of 20 senior mechanical engineering students, 18 males and two females, who served as the control group for this study. The class periods, other than weekly quizzes and the midterm, were spent in lectures and solving textbook-type problems. Most of these were solved by the professor with students copying from the board. Occasionally, problems were solved by students, with the professor fostering active learning techniques. Five of the class periods, totaling 250 min, were held in a computer lab where students learned to use MATLAB's control system toolbox. Most of the problems solved using MATLAB were textbook-type problems. One of the problems, solved by students in two- or three-person teams, involved designing and implementing a controller for the Quanser hardware (a rotary position control using PID). Time to solve the problem was limited to one class period, so the instructor provided guidance to students as necessary for them to complete the design before class ended.

B. Inverted Classroom

The second year of the study, the Control Systems course was taught using an IC. The IC class was composed of 20 senior mechanical engineering students: 16 males and four females. Students were expected to view video lectures outside of class time.

Video lectures were the primary means of disseminating course material to the students. The videos included audio of the instructor explaining the material and a live screen capture of the instructor writing equations on a tablet computer. To cover the course content, there were 45 videos, each between 5 and 15 min long. The videos were edited and shortened to this length by removing pauses in the presentation that occurred while writing or while explaining the material. The real-time length of the presentation was approximately twice the final video length. Each video took approximately 1 h to record and 1–2 h to edit. The videos were posted on YouTube (YouTube channel MEGR438) so they were easily accessible to students. Specific videos were not assigned. Instead, students were given sample quizzes and, in conjunction with the assigned homework, were expected to identify and watch videos relevant to the material for the week.

The class time, other than weekly quizzes and exams, was spent solving problems, either individually or in groups. All classes, except for exams, were held in a computer lab where students used MATLAB's control system toolbox to solve selected problems. This is in contrast to the TC, where MATLAB was used in only five class periods. The IC used the same problems used in the TC. However, rather than being solved by the instructor, these problems were solved by the students during class. In the IC course, the instructor would pose a simple problem, such as drawing the root locus for a given system, and allow a short time for students to start to solve the problem and identify what they did not understand. The instructor would then ask a student to present his/her solution approach. Afterwards, the instructor would hold a short discussion to clarify key concepts. Several such problems were solved in each class period. In addition, students worked in groups of two to three on four large open-ended problems: two PID designs, a lead/lag design, and a full-state feedback design. While students were working on these problems, the instructor would circulate among groups and clarify concepts. The open-ended nature of these problems sometimes required students to learn and apply concepts not yet practiced in class or on homework. In one of the PID design problems, for example, students were shown a physical system consisting of a dc motor, optical encoder, and gear train (Quanser). The problem was posed as follows: "Design a position controller for the system and then simulate the system response." The problem required students to think about how to model the system, what type of performance specifications they should use for the design, and what type of controller was appropriate. They then used that approach to solve the problem. Students spent two to three days on each open-ended problem.

C. Assessment Methods

The effectiveness of the IC was evaluated by comparing content coverage, quiz and exam performance, and student perception of teaching, learning, and the inverted classroom format. Procedures used to collect and compile data were approved by the university's Internal Review Board. During each of the two course offerings, grades were recorded for every quiz and exam problem for every student. There were 35 quiz or exam problems in the TC group, and 46 quiz or exam problems in the IC group. The larger number of questions in the IC course stemmed from the fact that the course progressed faster and so covered more material.

Problems used in the analysis were selected by matching problems in each course that addressed identical course outcomes, had a similar question format, and were given at approximately the same time during the quarter. Problem timing was considered to eliminate bias; for example, even if a final problem was identical to a midterm problem, students would have had extra experience with that material by the time of the final and thus were likely to perform better on the final than the midterm. The problem matching was done independently by the course instructor, by a coauthor, and by an adjunct faculty familiar with control systems. These independent matches were compared, and only those problems that all agreed were good matches were analyzed for this paper.

Seventeen problem pairs were matched between the IC and TC offerings: eight from quizzes, five from midterms, and four from final exams. The problems were analyzed both individually and when grouped with other problems covering the same topics or outcomes. For example, students' performance on individual problems dealing with analysis of open-loop systems was considered, along with students' aggregate scores on all open-loop analysis problems. Problems that involved design were also grouped. This resulted in seven groups or types of problems.

At the end of both courses, the Department administered an anonymous written survey of student perception of teaching. The survey asks students to rate, on a five-point Likert scale, the course organization, the instructor's use of class time, attitude and teaching style, the effectiveness of exams or reports, the students' personal effort, and the approximate number of hours per week spent studying for the course.

An additional assessment in the IC course measured student perceptions of learning and the class format in the fourth and 10th weeks of the quarter. The survey contained 15 questions with a five-point Likert scale and space for additional comments. Following the survey, students participated in an in-class discussion facilitated by a faculty member not teaching the course; the professor teaching the course was not present during the discussion.

III. Results

A. Group Similarity

To help identify any *a priori* differences between the IC and TC student groups, their performance in two past courses was compared. All the students took both of these courses exactly two quarters prior to taking the Control Systems course and were taught by the same instructors, with the same books, and in the same format. Grade-point average (GPA) and number of course credits were also compared for the IC and TC groups at the time of graduation, one quarter after taking Control Systems. There was no statistical difference between the two groups, suggesting that the IC and TC groups were very similar in background and ability prior to the Control System course. Nonetheless, where applicable, GPA and course grades were used as a covariant in statistical analysis.

B. Content Coverage

Content coverage was compared in the TC and IC offerings. The comparison considered the first time the topic was assessed through a quiz or exam and thus when students were expected to have learned the material. By the fourth week, the IC offering was already ahead of the TC offering. By the end of the 10-week quarter, the IC course was one week ahead of the TC course and had covered two topics not covered in the TC offering: full-state feedback design and Ackermann's formula. Furthermore, students in the IC course solved four open-ended design problems versus one in the TC.

C. Student Quiz and Exam Performance

To evaluate the effectiveness of the IC, students' performance on the matched problems in the IC and TC courses was compared. For each problem and problem group, a t-test was used to determine if there was a statistical difference between the IC and TC means. The means were also compared to the GPA or grades from previous courses as covariants. Because the results from these analyses did not change the results in any noticeable way, only the simple analysis without the covariants is presented. The results are shown in Table I.

The IC group performed statistically better ($p \leq 0.003$) on problem sets involving open-loop analysis, root locus-based design, and Bode plot-based controller design. The IC group also performed statistically better than the TC group ($p = 0.001$) on design problems (aggregated scores for root locus, algebraic, and Bode-based design). All other comparisons were nonsignificant, indicating that the IC and TC students scored similarly.

D. Student Perception of Teaching

The departmental assessment showed that end-of-quarter student perception of teaching for the two courses was similar. However, the IC class gave a higher rating (mean $M = 4.65$, standard deviation $SD = 0.49$) than the TC class ($M = 4.21, SD = 0.79$); t-test with $n = 37$, $t(37) = -2.105$,

TABLE I
COMPARISON OF QUIZ AND EXAM QUESTIONS GROUPED BY TOPIC

Problem	TC Mean (SD)	IC Mean (SD)	P value
Ladder Logic (1 problem)	8.20 (2.21)	8.15 (2.01)	0.941
Open Loop (5 problems)	8.34(0.70)	9.09 (0.71)	0.002*
Open Loop 1	8.25 (1.37)	8.75 (1.71)	0.315
Open Loop 2	8.90 (0.97)	9.30 (0.73)	0.149
Open Loop 3	7.13 (1.73)	8.65 (0.93)	0.001*
Open Loop 4	9.40 (1.01)	9.07 (1.07)	0.318
Open Loop 5	8.03 (2.20)	9.70 (6.30)	0.004*
Root Locus (2 problems)	9.04 (0.78)	9.30 (0.70)	0.277
Root Locus 1	9.38 (0.57)	9.83 (0.42)	0.007*
Root Locus 2	8.70 (1.59)	8.77 (1.36)	0.887
Root Locus Design (3 problems)	7.79 (0.96)	8.79 (0.97)	0.003*
Root Locus Design 1	9.00(.09)	9.00 (1.38)	1.000
Root Locus Design 2	7.88 (1.11)	7.87 (1.26)	0.986
Root Locus Design 3	6.50 (2.01)	9.46 (1.27)	<0.001*
Algebraic Design (1 problem)	9.55 (1.00)	9.25 (0.85)	0.313
Bode-Based Design (3 problems)	6.72 (0.94)	8.25 (1.30)	<0.001*
Bode-Based Design 1	5.60 (1.85)	8.45 (1.61)	<0.001*
Bode-Based Design 2	5.57 (1.74)	7.50 (2.06)	0.006*
Bode-Based Design 3	8.80 (1.44)	8.80 (1.47)	1.000
Nyquist Stability (2 problems)	7.68 (1.41)	7.52 (1.94)	0.770
Nyquist Stability 1	8.00 (1.81)	7.33 (2.56)	0.347
Nyquist Stability 2	7.35 (2.21)	7.70 (2.03)	0.605
Design (Root Locus, Algebraic Design, Bode Based)	7.58 (0.75)	8.61 (0.98)	0.001*

** Statistically significant results, p<0.05*

$p = 0.042$, to the statement, "The instructor appropriately assessed learned skills through exams or reports, etc." where $5 = \text{Strongly Agree}, 4 = \text{Agree}, 3 = \text{Neutral}, 2 = \text{Disagree}, 1 = \text{Strongly Disagree}$. The survey also asked students to estimate the number of hours that they spent studying per week ($1 =< 5$ h, $2 = 5$–6 h, $3 = 7$–8 h, $4 = 9$–10 h, $5 => 11$ h). Surprisingly, the IC group reported studying significantly less each week over the course of the term than the TC group, $t(37) = -4.695, p < 0.001$. The IC mean of 2.25 $(SD = 0.84)$, corresponds to about 5.5 h per week, whereas the mean for the TC group of 3.47 $(SD = 0.79)$ converts to about 8 h per week.

In the IC course, 14 of the 20 comments relating to what the students liked in class pointed to the usefulness of the online videos, and five of the 20 comments stated that in-class design projects and examples contributed to their understanding of the concepts. In the IC course, four of the 17 comments asked for a more structured course organization. In the TC offering, seven of the 14 of the written comments that suggested improvement asked for more lab time.

E. Student Perceptions of the Inverted Classroom

The survey used to measure students' perceptions of the IC showed that students recognized that the new format required self-discipline and necessitated some adjustment to their study habits. By week four, students felt that the IC was a better use of class time and that the format better prepared them for engineering practice.

Students rated videos and class time as stronger contributors to their learning than the homework. Over the quarter, students watched the videos increasingly often; students reported watching each video on average 2.41 times $(SD = 1.00)$ in the fourth week and 2.88 times $(SD = 0.99)$ in the 10th week $(p = 0.056)$. Across the quarter, there was a significant decrease in the judged effectiveness of reading assignments $[M_{4\text{th}} = 2.65\ (SD = 0.93), M_{10\text{th}} = 2.18\ (SD = 0.81), p = 0.027]$, and an increase in the perceived effectiveness of class time $[M_{4\text{th}} = 3.41\ (SD = 1.23), M_{10\text{th}} = 4.24\ (SD = 0.75), p = 0.026]$, where $1 = \text{not effective}, 3 = \text{typical}, 5 = \text{very effective}$.

Thirty-one percent of students felt the IC was appropriate to only senior classes, 32% to junior and senior classes, and 37% to sophomore, junior, and senior classes. No student thought it would work in a first-year setting.

During the in-class discussion in the fourth week of the quarter, students stated that they were initially frustrated with the IC, but were learning to adjust to the need to come to class prepared. Students stated that they liked being able to rewatch sections of the videos that were unclear on the first viewing. During the 10th-week discussion, students mentioned that this format might not work in a course with many new concepts because students would struggle to identify where to apply the various new concepts and equations.

IV. DISCUSSION

Results of the study were promising and highlight the benefits and challenges of using an inverted classroom in an engineering setting. The results are particularly relevant given the scarcity of published research on the use of an IC in an upper-division engineering course.

One of the most surprising results was that the IC format allowed the instructor to cover more course material than in a TC. These findings corroborate those of Bland [20]. One could argue that the reason more material is covered in an IC is because students are actually spending more time on the course. This appears, however, not to be the case in the present study; students in the IC group reported spending significantly fewer hours per week studying outside of the classroom than their TC counterparts. These results suggest that, when used in conjunction with an IC format, active, cooperative, and problem-based learning may not require the instructor to sacrifice course content, nor will it place a greater study burden on students.

Comparisons of student performance on quiz and exam questions were also promising. Of the 17 matched problems, the IC group performed as well or better on all problems. When looking at the problems aggregated by type, the IC group performed statistically better on three of the five types—open-loop analysis, root locus-based design, and Bode-based design. The IC group also performed better on problems involving design. This finding is consistent with the fact that the IC offering placed more emphasis on design and problem solving than did the TC offering. However, it should be noted that it was the performance on only a few problems within each group that contributed substantially to the significant differences. The key finding from this is that the IC classroom at best improved students' understanding of engineering concepts, and at worst "did no harm." These findings are consistent, or better, than the findings of other studies [16], [18], [23], [28].

Student perceptions of teaching, as measured by the departmental end-of-quarter survey, showed only two significant differences. First, IC students reported spending less time studying outside of class than TC students. The latter finding contradicts the results of another IC study where IC students reported that the course required extra time [16]. It could be that the IC students did not interpret their out-of-class activities as "studying." Thus, even if students in the IC course were spending more time outside of class, watching a video may be perceived as either taking less time than working through online problems or not as "studying" per se. An IC can certainly be characterized as more efficient with respect to lecturing since time spent receiving the lecture content is at least half that of the traditional classroom (due to compression of lectures through video editing), and students have the opportunity to pause and rewatch the lectures as many times as they need to, actions they perceived as key to their learning.

The other significant difference was that the IC students gave significantly higher ratings than TC students to the statement, "The instructor appropriately assessed learned skills through exams or reports, etc." This is interesting because there was no difference in the way the two courses were assessed. The timing and length of quizzes and exams were essentially identical. One possible explanation is that the IC students were more confident in their abilities at the time they took the quizzes and exams and so felt the assessments better reflected their skills. Indeed, IC students commented on their confidence in the material at the end of the quarter.

Issues with course structure were a reoccurring theme with students. The instructor, too, observed that students often expressed frustration with the course structure and having to decide for themselves which videos they needed to watch. This was especially true with students who typically performed well in engineering classes. This desire for structure corroborates findings of others [24], [25]. Some students were overwhelmed with the number of resources available to them and needed help identifying specific videos to watch. Even though the intent was for students to search for information themselves in order to help develop lifelong learning skills and more closely approximate a real-world environment, the authors recommend that in students' first IC course instructors begin with some structure and guidelines; these can be reduced gradually and eventually removed.

Surveys and in-class discussions suggested that students needed some time to adjust to the IC format, but that the period for adjustment to the IC format was fairly short. By the fourth week, students seemed to have realized that they would learn more during class time if they came prepared. This behavior indicates self-regulation, which has been shown to increase learning gains and exam performance [30]. A student's ability to accept personal responsibility for learning is an essential part of intellectual development and preparation for engineering practice. Advancing students to that level by the time they graduate should be a goal of engineering curricula [8].

The authors do not agree with the students' skepticism about the effectiveness of an IC for courses that introduce new concepts. Students underestimated the number of new concepts, such as root locus and frequency domain analysis, that they learned in Control Systems. Using too many equations and knowing where to apply them (a concern voiced during the in-class discussion at the end of the quarter) is precisely the reason for using problem-based learning method in these courses.

Students in general felt that freshmen did not have the academic maturity needed to succeed in an IC setting. Their perception agrees with the findings of Strayer [24] and Baker [26]. Given the initial struggles of the seniors noted by the survey and in-class discussion, and observed by the instructor, the authors concur that an IC format may be difficult for students who have not developed strong study skills. However, others have reported success with an IC in sophomore courses [16], [30]. Given the potential benefits of an IC, as reported in this paper, and the lack of research regarding the applicability of an IC to first-year courses, future studies should investigate use of an IC in a first-year course.

Finally, the implementation of the IC initially requires a substantial time investment. Over 100 h were spent creating videos for this four quarter-credit course. Additional time was required to identify and develop problems for in-class learning activities. However, once the course material was developed, the instructor spent less time preparing before each class period than in the TC offering. Future offerings of the course will require substantially less preparation since videos and class activities can be reused from year to year.

V. Conclusion

An inverted classroom was applied to a senior-level course in the undergraduate mechanical engineering program. Students' exam performance and teaching perceptions were compared to the same course offered in a traditional, lecture-style setting to a similar student cohort. The results of this study are encouraging. The IC concept provided a platform for class time to be used for individual and group problem solving. Not only was the instructor able to cover more material in the IC class than in the lecture class, but students also demonstrated equal or better quiz and exam performance and better scores on design problems, adopted to the format fairly quickly, and showed equal or greater satisfaction.

Engineering education should produce graduates who have good problem-solving skills, are able to solve open-ended problems, and have strong technical knowledge and an ability to learn on their own. An inverted classroom can play a key role in a modern engineering education by freeing time for learner-centered activities and encouraging students to become independent self-learners.

References

[1] National Academy of Engineers (NAE), *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC, USA: National Academies Press, 2004.

[2] National Academy of Engineers (NAE), *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*. Washington, DC, USA: National Academies Press, 2005.

[3] R. Adams, D. Evangelou, L. English, A. D. Figueiredo, N. Mousoulides, A. Pawley, C. Schifellite, R. Stevens, M. Svinicki, J. M. Trenor, and D. M. Wilson, "Multiple perspectives on engaging future engineers," *J. Eng. Educ.*, vol. 100, no. 1, pp. 48–88, 2011.

[4] L. H. Jamieson and J. R. Lohmann, "Creating a culture for scholarly and systematic innovation in engineering education: Ensuring U.S. engineering has the right people with the right talent for a global society," ASEE, Washington, DC, USA, 2009.
[5] S. D. Sheppard, K. Macatangay, A. Colby, and W. M. Sullivan, *Educating Engineers: Designing for the Future of the Field*. San Francisco, CA, USA: Jossey-Bass, 2008, ch. 3.
[6] R. M. Felder and R. Brent, "The intellectual development of science and engineering students. I. Models and challenges," *J. Eng. Educ.*, vol. 93, no. 4, pp. 269–277, 2004.
[7] M. Prince, "Does active learning work? A review of the research," *J. Eng. Educ.*, vol. 93, no. 4, pp. 223–231, 2004.
[8] M. Prince and R. M. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," *J. Eng. Educ.*, vol. 95, no. 2, pp. 123–138, 2006.
[9] T. A. Litzinger, L. R. Lattuca, R. G. Hadgraft, and W. C. Newsletter, "Engineering education and the development of expertise," *J. Eng. Educ.*, vol. 100, no. 1, pp. 123–150, 2011.
[10] R. M. Felder and R. Brent, "The intellectual development of science and engineering students. II. Teaching to promote growth," *J. Eng. Educ.*, vol. 93, no. 4, pp. 279–291, 2004.
[11] R. M. Felder, R. Brent, and M. Prince, "Effective instructional development strategies," *J. Eng. Educ.*, vol. 100, no. 1, pp. 89–122, 2011.
[12] R. G. S. Matthew and D. C. Hughes, "Getting at deep learning: A problem-based approach," *Eng. Sci. Educ. J.*, vol. 3, no. 5, pp. 234–240, 1994.
[13] S. Zappe, R. Leicht, J. Messner, T. Litzinger, and H. W. Lee, ""Flipping" the classroom to explore active learning in a large undergraduate course," in *Proc. ASEE Conf.*, Austin, TX, 2009, p. AC2009-92.
[14] A. Dollar, "ASEE Annual Conference 2011, Main plenary," Feb. 2013 [Online]. Available: http://www.it.uu.se/research/group/upcerg_new/events/ASEE2011_resources/plenary_slides.pdf
[15] G. Gannod, J. Burge, and M. Helmick, "Using the inverted classroom to teach software engineering," in *Proc. Int. Conf. Softw. Eng.*, Leipzig, Germany, May 2008, pp. 777–786.
[16] C. Papadopoulos and S. A. Roman, "Implementing and inverted classroom model in engineering statics: Intial results," in *Proc. ASEE Annu. Conf.*, Louisville, KY, USA, 2010, p. AC2010-1868.
[17] L. Bland, "Apply flip/inverted classroom model in electrical engineering to establish life-long learning," in *Proc. ASEE Annu. Conf.*, Chicago, IL, USA, 2006, p. AC2006-856.
[18] J. Day and D. Foley, "Evaluating a web lecture intervention in a human-computer interaction courses," *IEEE Trans. Educ.*, vol. 49, no. 4, pp. 420–431, Nov. 2006.
[19] C. Demetry, "Work in progress—An innovation merging 'Clasroom flip' and team-based learning," in *Proc. 40th ASEE/IEEE Frontiers Educ. Conf.*, Arlington, VA, USA, 2010, p. T1E-1.
[20] C. Haden, P. Flikkema, T. Weller, J. Frolik, W. Verrel-Berenback, and W. Shiroma, "The assessment of a hybrid on-line/in-class course developed at multiple universities," in *Proc. ASEE Conf.*, Austin, TX, USA, 2009, p. AC2009-246.
[21] R. Toto and H. Nguyen, "Flipping the work design in an industrial engineering course," in *Proc. 39th ASEE/IEEE Frontiers Educ. Conf.*, San Antonio, TX, USA, 2009, p. T4F.
[22] M. Lage, G. Platt, and M. Treglia, "Inverting the classroom: A gateway to creating an inclusive learning environment," *J. Econ. Educ.*, vol. 31, no. 1, pp. 30–43, 2000.
[23] S. Kellogg, "Developing online materials to facilitate and inverted classroom approach," in *Proc. ASEE/IEEE Frontiers Educ. Conf.*, San Antonio, TX, USA, 2009, p. T3F.
[24] J. Strayer, "The effects of the classroom flip on the learning environment: A comparison of learning activity in and traditional classroom and a flip classroom that used and intelligent tutoring system," Ph.D. dissertation, Dept. Educ., Ohio State Univ., Columbus, OH, USA, 2007.
[25] N. Fredrickson, P. Reed, and V. Clifford, "Evaluating web-supported learning verses lecture- based teaching: Quantitate and qualitative perspectives," *Higher Educ.*, vol. 50, pp. 645–664, 2005.
[26] J. W. Baker, "The 'Classroom flip': Using web course management tools to become the guide by the side," in *Sel. Papers 11th Int. Conf. Coll. Teaching Learning*, J. Chambers, Ed., Jacksonville, FL, USA, 2000.
[27] F. Golnaraghi and B. Kuo, *Automatic Control Systems*, 9th ed. Hoboken, NJ, USA: Wiley, 2010.
[28] M. Rais-Rohani, A. Walters, and A. Vizzini, "Emporium based redesign of statics: An innovative approach to enhance learning and reduce costs," in *Proc. ASEE Annu. Conf.*, Louisville, KY, 2010, p. AC2010-610.
[29] Quanser, Inc., Markham, ON, Canada, "Quanser," Feb. 2013 [Online]. Available: http://www.quanser.com
[30] P. Stief and A. Dollar, "Web-based statics course: Study of usage patterns and learning gains," *J. Eng. Educ.*, vol. 98, no. 4, pp. 321–333, 2009.

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