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An Assessment of Student Learning, Perceptions, and Social Capital Development in Undergraduate, Lower-division STEM Courses Employing a Flipped Classroom Pedagogy

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Introduction

The flipped classroom is attracting considerable attention in the academic world at both the K-12 and college level, as evidenced by a number of recent articles.[1, 11] However, rigorous research on student outcomes is still sparse.[2, 6] While a few studies indicate student success in upper division STEM courses,[8,10] questions remain about whether or not students in lower-division courses, particularly freshmen, have the study skills required to succeed in flipped classrooms, where preparation prior to class and self-motivated learning is required.

These incoming students are at particularly high risk for attrition from STEM fields for a variety of reasons, including uninspiring introductory courses, difficulty with math, and an unwelcoming academic culture.[5] The flipped classroom structure may provide a venue for mitigating some of these issues. Additionally, the development of social capital, which has been shown to have positive benefits for student success and retention, has the potential to be increased in a flipped classroom model.

A pilot study, performed on a freshman level introduction to electrical engineering course using a flipped pedagogy, assessed learning gains through a pre- and post-concept inventory and historical data on exam scores.[13] In addition, students were surveyed about their use of course resources, collaboration in class, and perceptions and attitudes. The study revealed that while freshman students in the course did not watch the pre-recorded lectures prior to class as often as older students, they did tend to work collaboratively with other students more often than older students. Overall learning gains were similar to historical levels. Building on this pilot study, the current study extends the assessment to other lower-division undergraduate STEM courses where instructors have chosen to use flipped classroom pedagogy.

The research questions posed in this study are:

1. How does student learning, particularly for freshman and sophomores, compare between traditional and flipped STEM classrooms?
2. Do students, particularly freshman and sophomores, perceive a benefit from the flipped classroom environment?
3. Does the flipped classroom environment promote the development of social capital, particularly among freshman and sophomores?

This paper details initial data analysis and findings from STEM courses taken by underclassmen (freshman and sophomore) students at a northern United States university where a flipped pedagogy has been employed. While freshman students are the desired study group, finding enough freshman-level STEM classrooms employing a flipped pedagogy to study is a challenge. Therefore, rather than focus on a single group of students in one course, this research incorporates data from multiple courses and examines differences between upperclassmen and underclassmen in an attempt to generalize the results.

Background

The flipped (or inverted) classroom is defined by Lage et al., [7] who state that, "inverting the classroom means that events that have traditionally taken place inside the classroom now take place outside the classroom and vice versa" (p. 32). In the context of a STEM classroom, this means that traditional lecture material that would have been delivered during class time is now delivered outside the classroom, often via instructor-prepared, pre-recorded video lectures. Student problem solving through homework may still be completed outside of the classroom, but in class activities focus more on collaborative, active learning exercises that engage students in real time. The implementation of the flipped classroom pedagogy varies significantly among instructors and disciplines.

One of the goals of this study is to evaluate the potential of the flipped classroom environment to facilitate development of social capital among students. In 2001, Etcheverry, et. al.[4] showed that social capital has a positive effect on the retention and academic achievement of students. Etcheverry defines social capital as consisting of exchanges that arise through the interactions between students and professors and among students as they cooperate in learning the material. Research in social capital in engineering education is still mostly unknown. Brown, et al.[3] investigated social capital in a sophomore electrical engineering lab and found that need and lack of resources were key aspects that helped develop social capital. He then asks the questions, "… should engineering curriculum and laboratories be designed to encourage the development of social capital?" A more recent study by Martin et al.[9] explored the role of social capital on four Hispanic women pursuing engineering degrees. Martin's study concludes that "facilitating opportunities for students to develop sustained social capital may have potential to attract and retain underrepresented students in engineering".

Mason et al.[10] compared inverted and traditional lecture classrooms in an upper-division engineering course and found that in the inverted classroom (i) more material was covered and (ii) students learning outcomes were as good as or better than the traditional classroom. Mason et al. also indicated that students initially struggled with the new format and that the students felt that "freshman did not have the academic maturity needed to succeed in an [inverted classroom] setting" (p. 343).

A recent study by Love et al.[8] found that students in a linear algebra course employing the flipped classroom approach performed as well as their traditional lecture counterparts on exams, but also reported increased enjoyment of the course and a greater perceived relevance of the course material to their career. Students also reported an increase in the strength of their social network in the flipped section as opposed to the tradition section because of the structured peer interaction activities. The results of the study are significant for two reasons: first, improved student outcomes in introductory level STEM courses that students traditionally find very challenging may lead to increased student interest and retention, and second, this format may promote development of a social network that has been shown to be an important factor in the attraction and retention of women and underrepresented groups in STEM fields. While the results of the flipped classroom are promising, the authors state that "further research is needed in other disciplines, instructional contexts and by additional STEM educators, to more fully contribute to the instructional decision making being undertaken on college campuses today related to the use of flipped classroom environments" (p. 323).

Courses studied

Three STEM courses where flipped classroom pedagogy was employed were included in the current study. The course structure for each are briefly described below.

ES 346: Thermodynamics is a three credit lecture-based course required for a number of engineering degrees. Although thermodynamics is a 300-level course, many engineering students who meet the math and science prerequisites choose to take the course during their sophomore year. During Fall 2014, seventeen out of sixty survey respondents (28%) from the course reported having completed less than 60 credits of college-level coursework, and thus are considered underclassmen. Sixty-six students were enrolled in the course in Fall 2014, with 60 responding to the survey (90.9% response rate). The instructor had taught this course in a traditional lecture format for approximately ten years before employing a flipped pedagogy in Fall 2014.

The instructor prepared 45 lecture videos for a total of 9 hours, 23 minutes and 22 seconds of content. The average video length was 12 minutes and 30 seconds, with a maximum length of 21:13 and a minimum video length of 2:56. The pre-recorded lecture videos were narrated PowerPoint slides that were annotated, including complete examples worked out in real-time using the pen function. Recordings were created using Camtasia® and included audio/video narration by the instructor throughout the length of the video, with one self-test quiz problem at the end of each video. Students were encouraged to watch the pre-recorded lecture videos or read the textbook prior to coming to class as preparation for the in-class sessions, but were not required to do so.

Other course resources available to students through the course website were pencasts, a discussion forum, and homework modules. The instructor posted 17 pencasts, each providing a full solution to a calculation problem. Students could watch the pencast video and see the problem solved step by step with voice-over narration from the instructor, or simply view the solved problem. A discussion thread was also included on the course website where students could post questions and get responses from other students and the instructor. This feature was not used heavily during the course, with 5 total posts throughout the semester. Calculation-based, automatically graded homework assignments were assigned for completion outside of class time. Numerical answers were turned in by students directly through the course website with ten attempts to provide the correct response.

The in-class course structure consisted of mini-lectures and in-class questions posed to the group. Students logged their answers to the questions using Socrative.com®, a clicker system allowing the instructor to track student responses in real time. Class attendance and participation was mandatory and counted towards student grades. Students were encouraged to work with others when solving in-class problems, but not required to do so. Class sessions were recorded by video and posted to the course website as additional reference material.

CHEM 212: Analytical Chemistry is a four credit lab-based course required for all chemistry majors. Although CHEM 212 is a 200-level course, the students enrolled in the course were evenly divided among sophomores, juniors, and seniors. Thirteen students were enrolled in the course in the Fall of 2014, twelve of whom completed the course survey (92% response rate). Fall 2014 was the third time the instructor taught the course, having used flipped classroom pedagogy each of the three years.

The instructor prepared 48 video lectures for a total of 4 hours, 40 minutes and 4 seconds of content. The average video length was 5 minutes and 50 seconds, with the longest video at 12:53 and the shortest at 1:17. In addition, the instructor posted a number of review videos that covered material from general chemistry that students could use as needed to brush up on prerequisite material. Six review videos were posted, with an average length of 5 minutes and 34 seconds and a total of 33 minutes and 28 seconds of review content.

Various video recording and editing software were used to prepare the videos for the course. The general format for each video was direct recording of the instructor in an office environment while narrating in front of a series of whiteboards pre-prepared with lecture notes, chemical equations, and problems. Video was captured by the instructor using a mounted video camera. Screen shots of graphs, figures, data, and lecture notes were occasionally spliced into the videos of the instructor with voice-over narration. Numerous additional videos were prepared in support of the laboratory component of the course; however, that component of the course will be described and evaluated in a future paper.

Other references for the course included pencasts, worksheets, and sample exams. A total of 20 pencasts were posted, providing written solutions to calculation-based problems with the option to see video of the problems worked out step by step with full voice-narration by the instructor. Students were assigned a combination of videos, reading, practice problems and/or worksheet assignments as required pre-class work.

In-class activities principally consisted of mini-lectures, collaborative problem solving sessions, instructor-worked examples or homework problems, and student-worked homework problems. Additionally, throughout the course there would be clicker-style questions, case studies, enacting chemical principles, trivia-style games, and other ways for students to interact with the content.

EE102: Introduction to Electric and Computer Engineering is a three credit laboratory-based course that is required for electrical and computer engineering majors. Thirty-five students were enrolled in the course during Spring 2014, twenty-six of whom reported having completed sixty or less credits and are therefore categorized as under-classmen. Two students who completed the survey did not report the number of credits taken, and have therefore been removed from analysis when the data is divided between under-classmen and upper-classmen. The instructor had taught this course in a tradition lecture format for approximately ten years prior to employing an inverted pedagogy in the Spring 2014 semester.

The instructor prepared 18 video lectures for a total of 3 hours, 44 minutes and 3 seconds of content. The average video length was 12 minutes and 27 seconds, with the longest video at 18:53 and the shortest at 5:09. The pre-recorded lecture videos were created using Adobe Captivate®, and consisted of slides narrated by the instructor with interactive, problem solving quiz components included throughout the videos for student self-testing. Numerous additional videos were prepared in support of the laboratory component of the course; however, that component of the course will be described and evaluated in a future paper.

Students were expected to watch the pre-recorded video lectures before coming to class. In addition, students were expected to complete calculation-based, automatically graded homework assignments on a periodic basis. In-class activities principally consisted of mini-quizzes, small group activities, problem-solving sessions and collaborative work on labs and homework. Mini-quizzes were given at the beginning of most class sessions to gage students' conceptual understanding of the material.

Methods

The overall study design includes mixed-methods; however, the majority of the qualitative portion of the study design and data collection will be described in future papers. Students were administered online surveys composed of Likert-scale and open-ended questions. The survey instrument was designed to measure students' video use patterns, ease of video accessibility, preferences for study media, and social capital indicators along with demographic information. Although the survey was generalized as much as possible, specific questions within the instrument were adjusted for wording to reflect the resources, class activities, and specific terminology used for each course. Some survey questions were added to the instrument between the Spring of 2014 and Fall 2014. Specific wording for some of the survey questions followed Smith.[12]

When available, historic exam scores from traditionally-taught classes were compared with exam score data from current students who took the course with a flipped pedagogy. This data was available for ES 346 and for EE 102, but not for CHEM 212 since it had been taught using a flipped pedagogy each year. In all cases, historical and current exam data used for comparison were generated from the same courses taught by the same instructors.

Results and Analysis

Results relevant to the three research questions posed in the introduction: (1) student learning, (2) student preferences and perceptions, and (3) social capital development are presented below. Exam score and survey results are presented by course and, when possible, data was compiled from all three courses and sorted by class rank. Class rank was determined by students' self-reporting of the number of college credits completed at the time of survey, with those reporting less than 60 credits categorized as underclassmen and those completing 60 or more credits classified as upperclassmen.

Student Learning Assessment

Historic exam score data was available for comparison for ES 346 and EE 102 since the instructors had each taught the course using a traditional pedagogy until the most recent offering (Fall 2014 and Spring 2014, respectively). Both instructors report that while exact wording of exam questions changed from year to year, the scope, length and level of difficulty of the exams has remained constant and thus the exams are considered equivalent for comparison. As stated previously, historic exam scores could not be compared for CHEM 212 because the course has been taught using a flipped pedagogy each year it has been offered by the current instructor.

Average exam scores from 2014 (treatment group), 2013 and 2012 (control group) are reported by course in Figure 1. Exam score averages in 2014 were comparable to historic averages for EE 102. Average exam scores in ES 346, however, showed substantial gains. Exam score averages during the Fall of 2014 were 7%, 22%, and 15% higher than the highest exam average on each respective exam from the previous two years. Other variables, such as math preparation and prior thermodynamics knowledge, were not measured for these groups of students and therefore cannot be ruled out as potential influences. Continued study is needed to see if this trend continues. At a minimum, it can be argued that student academic performance as measured by exam scores did not suffer based upon the use of a flipped pedagogy in either class. Students who experienced the course using a flipped pedagogy scored as well or better than students in the same courses, with the same instructors, in the two years prior using traditional pedagogy. Unfortunately, historical exam score data could not be correlated to class rank; therefore, analysis of exams scores by class rank has not been included.

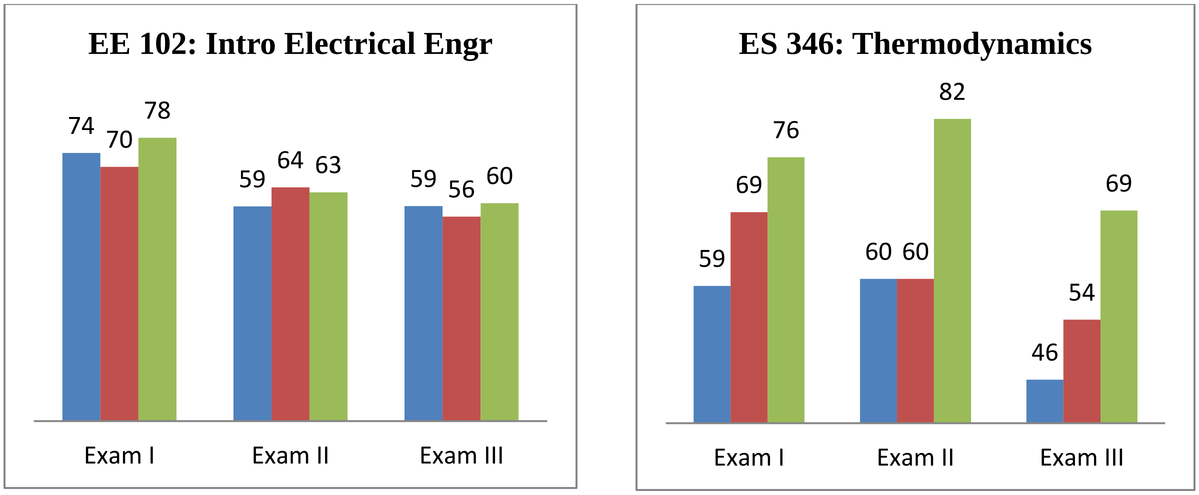

Figure 1. Average exam scores in ES 346 and EE 102 for 2012 (blue), 2013 (red), and 2014 (green). Each course was taught in a traditional lecture style during 2012 and 2013. A flipped classroom pedagogy was employed in 2014.

<u>Student Preferences and Perceptions</u>

Student survey results for selected questions indicating student preferences and perceptions are summarized by individual course (Figure 2) and by class rank (Figure 3) below.

Student responses to each of the preference questions posed showed similar trends of agreement/disagreement in most cases for each of the courses, but with some significant variations. Students generally disagreed with the statement that watching the videos was burdensome in terms of time, and agreed that videos were useful as a learning tool. Even so, students did not indicate a strong preference for pre-recorded lecture over traditional lecture. Only a minority of students (32% in ES 346, 33% in CHEM 212, and 19% in EE 102) agreed with the statement “I prefer content delivery by pre-recorded lecture to traditional lecture”. However, students expressed a strong preference for pre-recorded video lecture compared to reading a textbook, with 78% of students in ES 346 disagreeing (50% strongly disagreeing) and 50% of students in CHEM 212 disagreeing (17% strongly disagreeing) with the statement “I prefer to read a textbook rather than watch a pre-recorded video”. This trend was even more pronounced among underclassmen, with no freshman or sophomores indicating agreement with that statement, 75% indicating disagreement and 25% indicating neutrality.

Perhaps the most significant result is student response to the statement “I would like to take more classes using this teaching style”. Students from ES 346 in particular expressed overwhelming agreement with this statement, with 88% of students agreeing (78% strongly agreeing). Students from CHEM 212 were split on this topic, with 42% agreeing with the statement, 17% neutral, and 42% disagreeing. Underclassmen in particular were more likely to agree with this statement, with 90% of underclassmen agreeing (5% neutral, 5% disagree) compared with upperclassmen (77% agree, 15% neutral, 8% disagree).

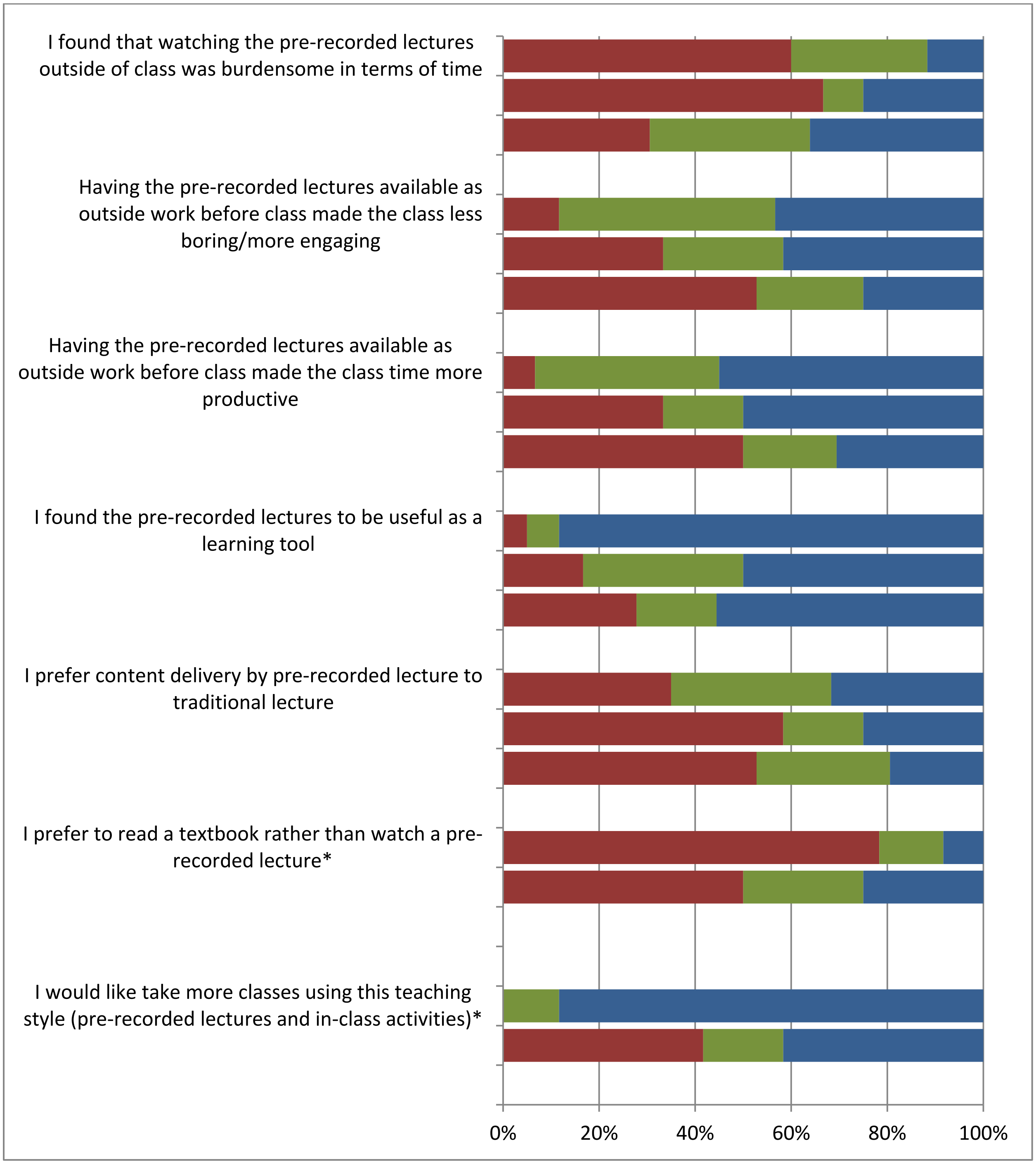

Figure 2. Student responses to selected perception survey questions by course. Red indicates disagreement, green represents neutrality, and blue represents agreement with each statement. The top bar in each cluster represents student responses from ES 346 (n=60), the middle bar is CHEM 212 (n=12), and the bottom bar is EE 102 (n=36). Questions denoted with an asterisk were not included in the EE 102 survey, thus only two bars are shown.

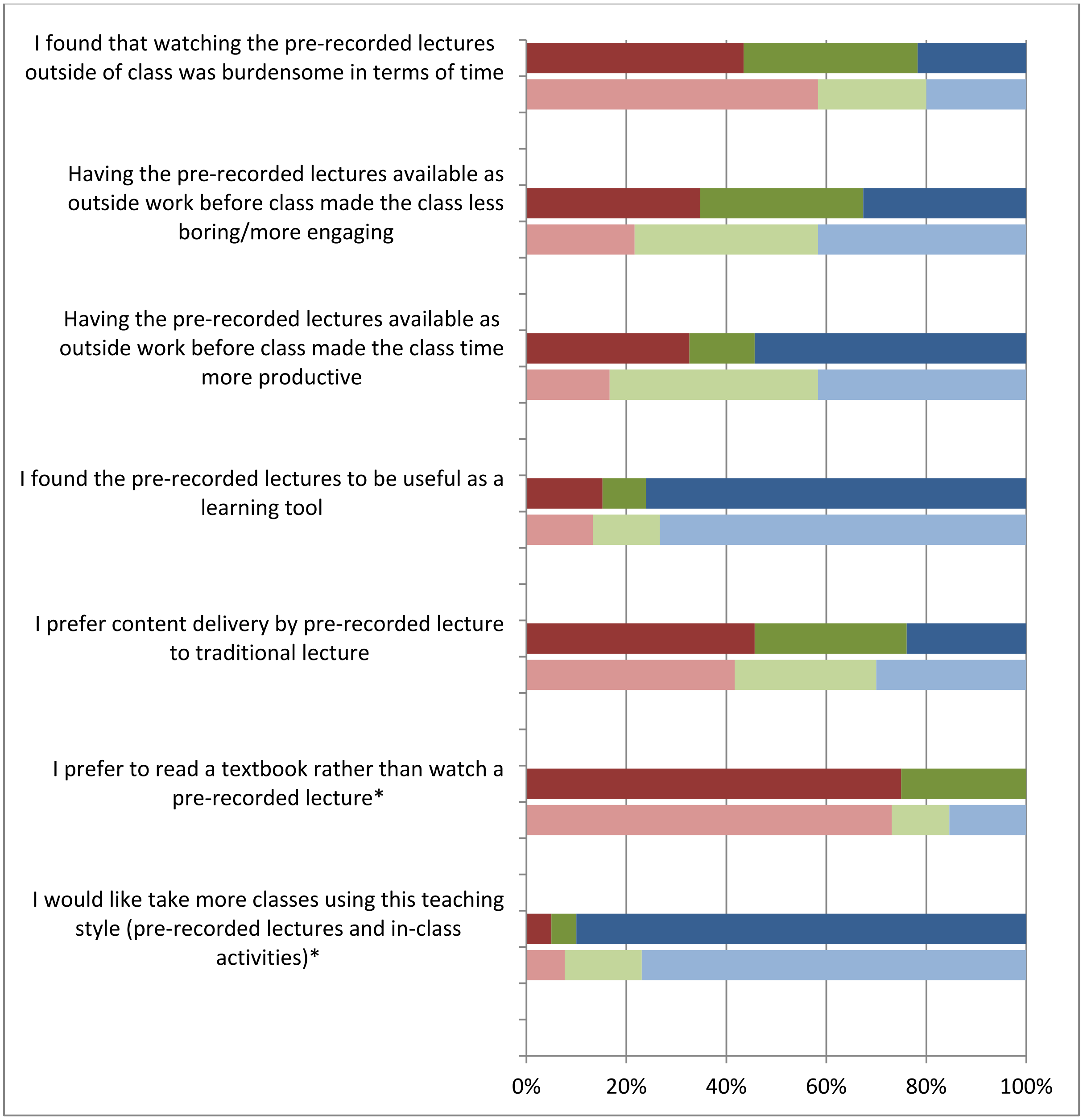

Figure 3. Student responses to selected perception survey questions by class rank. Red indicates disagreement, green represents neutrality, and blue represents agreement with each statement. The top bar in each cluster represents student responses from underclassmen (n=46), the bottom bar represents student responses from upperclassmen (n=60). Questions denoted with an asterisk were not included in the EE 102 survey, thus data have been adjusted for the total number of responses (n=20 and n=52 respectively).

Social Capital Indicators

Survey questions were posed to students in an attempt to measure social capital development. Survey results are summarized by individual course (Figure 4) and by class rank (Figure 5) below.

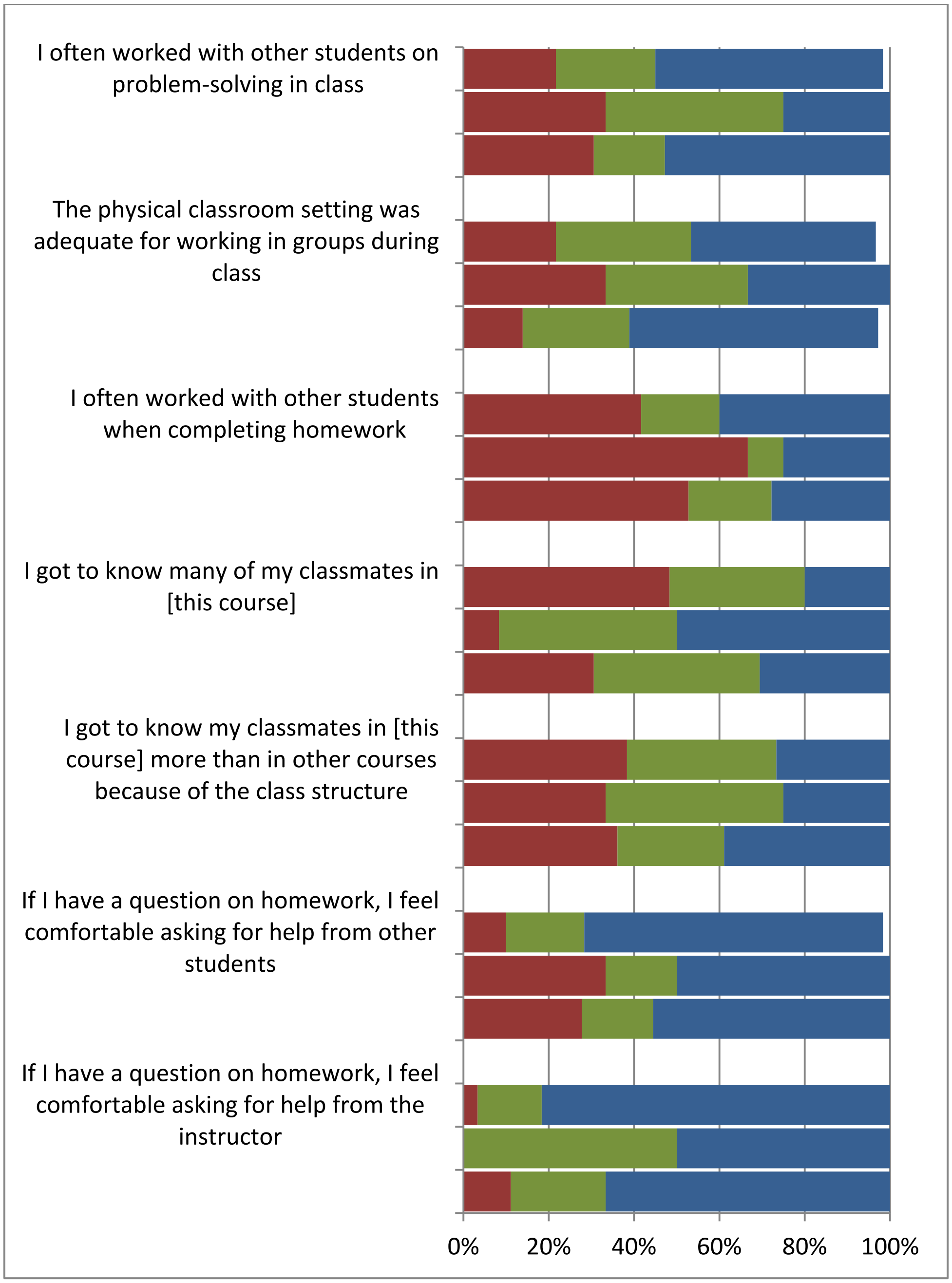

Figure 4. Student responses to social capital survey questions by course. Red indicates disagreement, green represents neutrality, and blue represents agreement with each statement. The top bar in each cluster represents student responses from ES 346 (n=60), the middle bar is CHEM 212 (n=12), and the bottom bar is EE 102 (n=36).

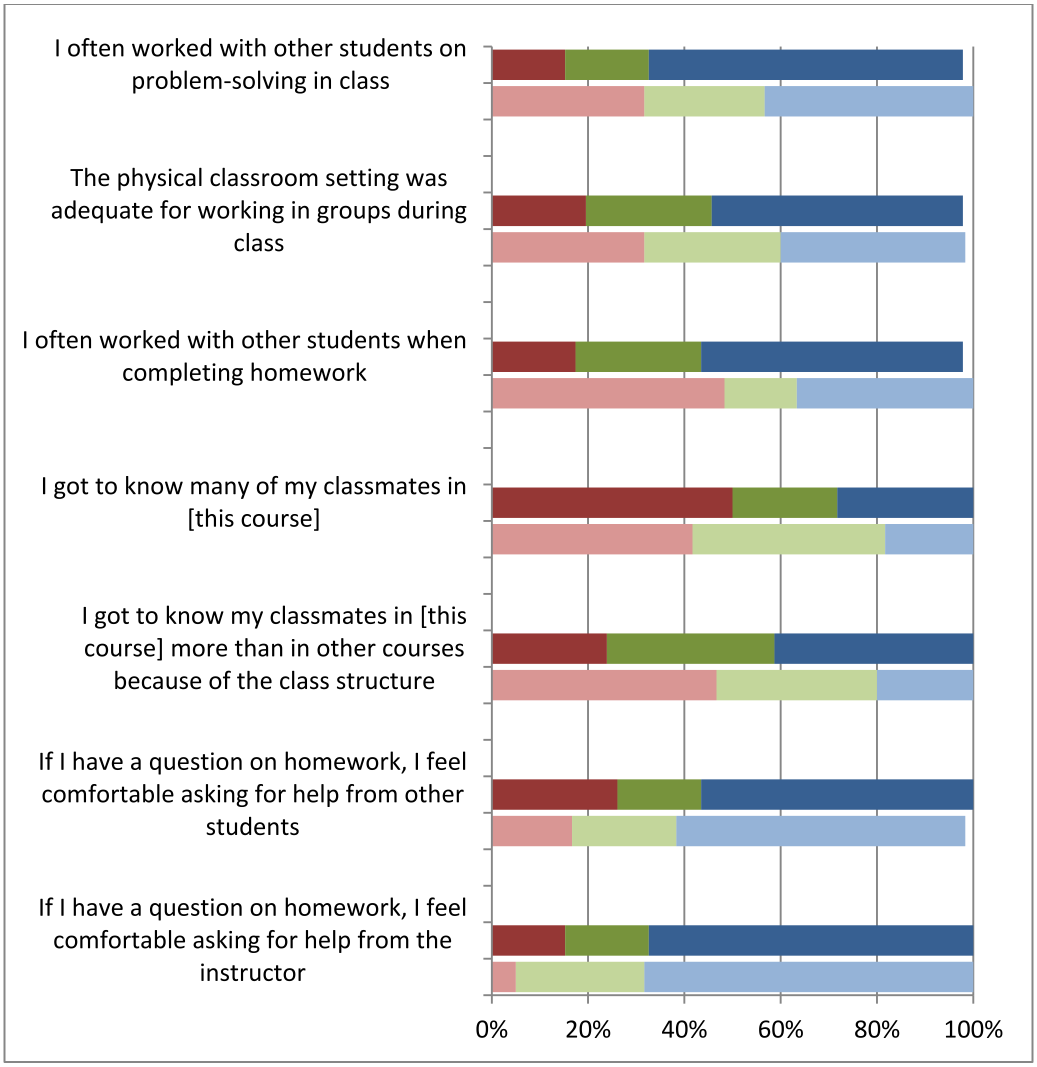

Figure 5. Student responses to selected perception survey questions by class rank. Red indicates disagreement, green represents neutrality, and blue represents agreement with each statement. The top bar in each cluster represents student responses from underclassmen (n=46), the bottom bar represents student responses from upperclassmen (n=60).

Students reported working with other students on problem solving in class in ES 346 (53% agree) and EE 102 (53% agree) more so than in CHEM 212 (25% agree, 42% neutral, 33% disagree), perhaps due to the different nature of the in-class activities in each class. A significantly higher percentage of underclassmen reported working with other students during class on problem solving (65%) than did upperclassmen (43%). However, students in CHEM 212 indicated getting to know many of their classmates more so than students in ES 346 and EE 102. While most students disagreed or were neutral on the statement "I got to know many of my classmates in [this course]", a higher proportion of the underclassmen agreed they "got to know their classmates in [this course] more so than in other courses because of the course structure"

(41% of underclassmen agree vs. 21% of upperclassmen agree). Students generally reported feeling comfortable asking other students or the instructor for help.

Conclusions and Implications for Future Studies

The results of this study indicate that students in STEM courses can be at least as successful academically, and potentially more so, in a flipped classroom environment compared to traditional lecture. This result is congruent with other studies in the literature[8, 10]. To facilitate analysis by class rank, longitudinal studies which track exam scores and learning assessments along with demographic data indicating class rank is suggested. In addition, pre- and post-concept inventories should be administered when at all possible to quantify students' incoming knowledge.

While students did not show a strong preference for pre-recorded lecture over traditional lecture, they did indicate quite clearly the preference for watching a video lecture as compared to reading a textbook. Therefore, if an instructor wants students to come to class prepared with content knowledge, they may have a better chance of this occurring with a video assignment compared to a reading assignment. This study also provides some evidence that underclassmen (freshman and sophomores) can be successful in the flipped classroom environment, and that underclassmen show a particular preference for video lectures and a strong interest in taking more classes using the flipped classroom teaching style. However, the majority of the students included in this particular analysis were sophomores, and thus these results may or may not apply to freshmen students.

Overall survey responses showed similar trends between underclassmen and upperclassmen, with the most significant difference noted within the social capital indicators. The underclassmen reported working with other students in class and on homework more often than their upperclass counterparts, and they reported getting to know their classmates in ES 346 more so than other courses because of the class structure at a higher level than upperclassmen. The flipped classroom appears to have some potential for supporting social capital development, particularly among underclassmen, although additional study is needed to evaluate social capital development within the classroom setting.

ES 346 appears to have been a particularly successful course transformation, with significantly higher average exam score averages and overwhelmingly positive feedback on the course structure. The common belief that students must be required to watch the videos using some type of graded assignment prior to class did not hold in this case. Students were only encouraged to watch the videos or read the text, and were successful regardless. Further investigation using qualitative methods is needed to identify and understand the successful components of the video and course structure, which may contribute to our understanding of best practices for flipped classrooms.

It is also important to note that a traditional lecture classroom does not equate to a "bad" learning environment, nor are all lecture courses equivalent. There are many variations in the level of engagement instructors can achieve with the lecture format, and many times instructors incorporate active learning exercises within a traditional lecture. Further description of the "before" (traditional) and "after" (flipped) classroom experience for each course is needed in order to provide a more complete picture of the true change in the learning environment.

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